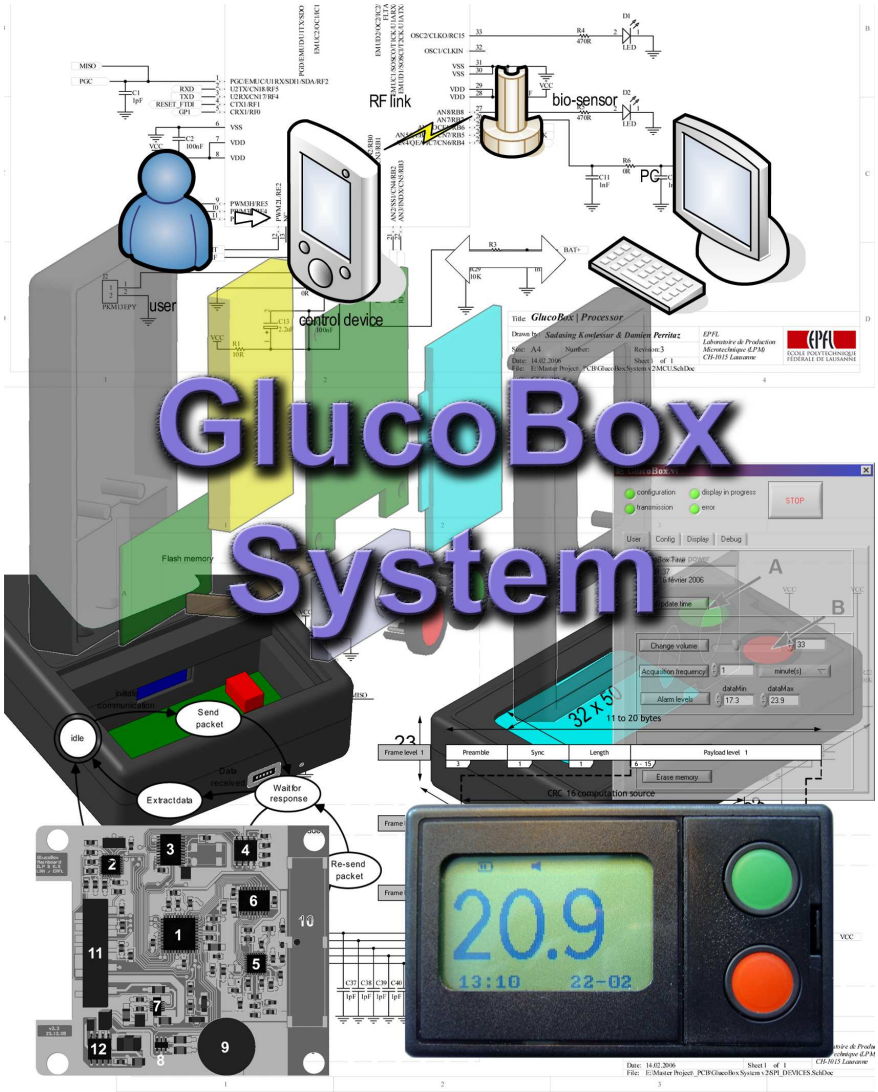
Master Project

LPM - IPR - STI

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Winter Session 2005-2006



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EIDGENÖSSISCHE TECHNISCHE HOCHSCHULE

SECTION DE MICROTECHNIQUE
LABORATOIRE DE PRODUCTION MICROTECHNIQUE

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TRAVAIL PRATIQUE DE MASTER

Microtechnique

Titre du travail:	GlucoBox System		
Candidat:	Damien Perritaz	**Section:**	Microtechnique
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Enoncé :
Lorsqu'il est implanté dans un patient, le capteur de glucose du LPM est contrôlé par un transceiver positionné à proximité du site d'implantation. Il est prévu que ce transciever soir lui-même contrôlé à travers une liaison RF par un boîtier externe avec afficheur et boutons de contrôle. Outre sa fonction de contrôle (programmation de la fréquence des mesures de glycémie, programmation des seuils d'alerte et des alarmes acoustiques et tactiles), ce boîtier assure aussi la fonction d'un "data logger" capable d'enregistrer toute une série de mesures, de les traiter (calculs de tendance) et de les visualiser. A terme, l'interopérabilité avec un PC ou un PDA devra être assuré. Ce boîtier de contrôle sera alimenté par batterie. Il devra être compact et un soin tout particulier sera porté quant à l'esthétique du boîtier. Il aura pour cœur un dsPIC de Microchip et la partie RF sera reprise d'un projet précédent. Le but de ce travail est de réaliser intégralement ce boîtier de contrôle: électronique, logiciel et design.

En outre les étudiants établiront d'une part la spécification du protocole de communication RF entre le boîtier de contrôle et le transceiver et d'autre part, contacteront des patients ainsi que du personnel soignant pour élaborer un cahier des charges fonctionnel de l'appareil.

Remarques :
Le candidat établira un planning de travail qui sera discuté à la fin des deux premières semaines de travail. Ce planning comprendra des échéances à dates fixes qui seront l'occasion de faire le point sur l'avance du travail et permettront éventuellement de modifier la démarche en fonction des objectifs à atteindre.

Un rapport dactylographié en 3 exemplaires comprenant en son début l'énoncé du travail suivi d'un résumé d'une page sera remis le 24 février 2006 à 12 heures au plus tard. La couleur n'est tolérée que sur des schémas qui ne seraient pas lisibles en noir.Un résumé d'une page sera établi selon le canevas pris sur le serveur du LPM et remis séparément au professeur (images et figures en noir et blanc, il sera édité dans une brochure).

Une défense de 45 minutes (environ 25 minutes de présentation et démonstration, plus 20 minutes de réponses aux questions) aura lieu dans la période du 13 au 20 mars 2006.

Le Professeur responsable L'assistant responsable

Lausanne, le 8 novembre 2005

GlucoBox System

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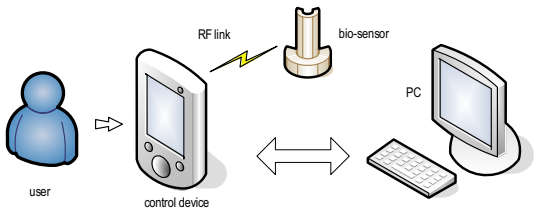
Introduction. A bio-sensor is currently under development at the LPM. The goal is to measure glucose level in blood of diabetic patients who need continuous glucose level monitoring. The objective of this project is to build a control device capable to communicate with the sensor and to transfer data to a PC. A request can be triggered by user or scheduled at a chosen frequency. The global concept is a system including the control device itself and a PC software: **GlucoBox System** is depicted in figure below.

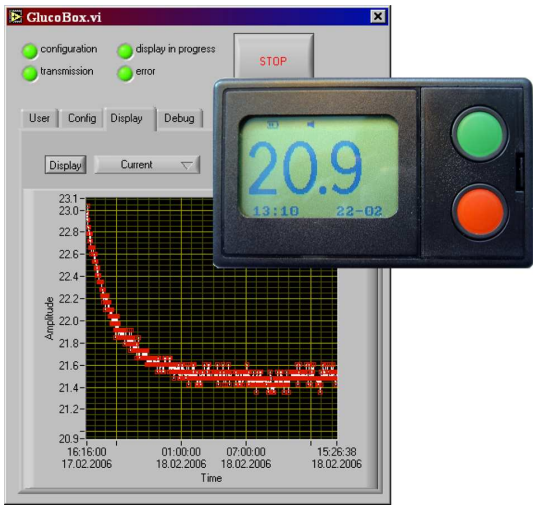


The project is divided into four main steps: research of solutions, design and manufacturing, software development and final tests.

Work. The starting point was to study existing solutions and to evaluate patients' needs. After having defined the project requirements, the selected solution was to build a custom-made system rather than using an existing host device.

Our work lead to user-friendly control device; by pressing a button, a reading is requested from the bio-sensor and the glucose rate is displayed within 5 s. If glucose level is out of normal range, an alarm resounds. The device can be scheduled to automatically request a reading without patient's intervention. Measurements are stored in the device itself. Later on, the patient can transfer all measurements to a PC via USB with the help of a user-friendly computer program. Data can then be exported for further analysis by a healthcare professional.

Results. Currently, all functional tasks are achieved, according to project requirements. However, only one main requirement has not been reached: RF range is less than the expected 3 m. In spite of poor RF performance, the concept of the GlucoBox System has been validated.



GlucoBox Control Device & Software

Main characteristics:

Dimensions	23 x 62 x 103 mm
Weight	115 g
Power autonomy	7 days
Storage capacity	85'000 measurements

Conclusion and future work. The GlucoBox System performance was evaluated and, compared to existing products, it fulfills many characteristics which make it a good foundation for the commercial product. Finally, we would like to point that for the next step, the RF part – which is essential in our concept – has to be improved.

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1 Introduction

At the LPM[1] laboratory, a bio-sensor is currently under development. The main goal of this sensor is to measure glucose level in blood by using a totally innovative method. The main application of this sensor is for diabetic patients who need glucose level monitoring.

1.1 What is diabetes ?

Diabetes is an illness which occurs as a result of problems with the production and supply of insulin in the body. Without insulin, our bodies cannot obtain the necessary energy from our food. Insulin is made in a large gland behind the stomach called the pancreas.

At present there is no cure for diabetes. In order to treat diabetes, the patient's instantaneous glucose level must be known. The most reliable measurement is actually done by analyzing the blood. The patient takes a blood sample and with the help of a glucometer, he can read its instantaneous measurement. Nowadays, portable glucometer helps patients to have a merely normal life style.

If glucose level is too high (hyperglycemia), the goal of treatment is to lower glucose level through medication in the form of insulin. On the other hand, if glucose level is too low (hypoglycemia), patient needs to eat sugar to restore glucose level.

The International Diabetes Federation[2] estimates that at least 194 million people in the world have diabetes.

1.2 Scope

One of the benefits of using the bio-sensor made by the LPM is to avoid patient from taking a blood sample. Indeed, the final form of the sensor is a miniature implant which needs only minor surgery intervention. At this stage of the development of the sensor, a prototype of the sensor exists. Moreover, a built-in RF[3] module will allow measurements to be sent to remote device for further analysis. The objective of this project is to build a control device capable of communicating with the sensor, in the frame of a demonstrator bench.

Results and the end of this project may be considered as important guidelines for a commercialized version of the control device.

[1] LPM: Laboratoire de Production Microtechnique, `http://lpmwww.epfl.ch/`
[2] `http://www.idf.org/`
[3] RF: Radio Frequency

1.3 PROJECT OVERVIEW

The proposed device is capable of requesting instantaneous reading of remote sensor via RF link and display measurement. Values can be stored in the device itself. Data can be transfered at any time to a personal computer (PC) for further analysis. Figure 1.1 depicts the general principle of the control device. Tasks such as scheduling measurements and loading parameters to the sensor are also possible.

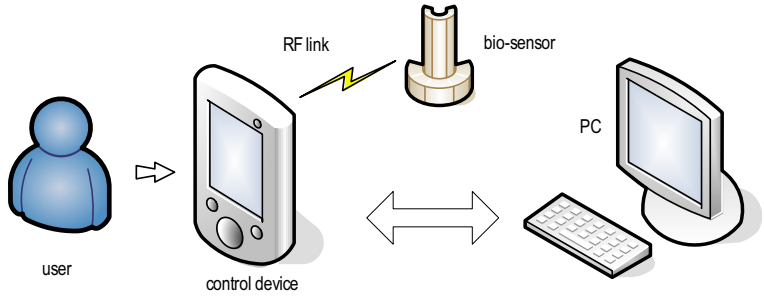

Figure 1.1: general concept of the control device

This project is held at EPFL as a winter master project, which lasts for sixteen weeks. The project is divided into four main steps: finding solutions, design and manufacturing, software development and final tests. As mentioned before, this project is for a demonstrator bench, so motivation is focused on the functionality of the device rather than its cost. Hence, there is apparently no cost constraints. Furthermore, industrialization aspects of the device are not taken into account in the design due to short duration of this project. For the same reasons, reliability, electrical and medical compliances are not part of this project.

1.4 PROJECT MANAGEMENT

This project is multi-disciplinary project. It requires knowledge in electrical design, mechanical design and programming. The work is lead by two students; both are from Microengineering section and have the necessary background to tackle each aspect of the project. In this context, no specific field was assigned to each student. Indeed, all the three fields are closely linked one to another and hence, the steps mentioned above were achieved on a combined-effort basis.

2 Basic concepts

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A glucose monitoring system is generally composed of three parts: a sensor gives glucose rate, a control device manages values given by the sensor and a computer software for post analysis. This chapter presents some usual glucose monitors with their specifications. With the recommendations of a healthcare professional, a list of requirements has been established for such systems.

Some suggested solutions were studied and a solution has been proposed, with the choices and their explanation. It is important to know that the study has been made on the basis that only a sensor exists.

2.1 State of the art

There is a huge potential market around medical devices. Approximately five billion CHF are invested every year for the development of glucose monitoring systems by a large number of firms. It is very difficult to obtain competitive devices. Several systems have been proposed, but only a few of them are currently used in Switzerland.

2.1.1 Accu-Chek® [1]

This system sold by Roche Diagnostics is the most used in Switzerland, and is commonly known to many diabetics. The patient usually manages himself his medication between medical appointments and can react according to his glucose level.

Patient takes his rate three to six times per day to check his level and takes medication if needed. For measurement, a small drop of blood is taken, (generally at the fingertip) with a reactive strip, and the latter is inserted into the device shown in figure 2.1(a). After five seconds, the glucose rate value is displayed on the screen, in a large number format. Date and time are also indicated. Then the patient must write the value on a notepad, for further analysis.

The system (including the device, the strips and the notepad) is usually kept in a little bag. Its size is about 180 x 100 x 30 mm and weighs 60 g. A compact version exists without the bag (115 x 56 x 30 mm). Moreover, the device has the capability to store up to five hundreds measurements. The patient or the doctor[1] can transfer data to a computer for analysis, via an infrared connection to an adapter connected to the computer. A software is available for the patient to help him to manage and analyze his measurements.

The whole system, is an effective manner to regulate glucose rate. Indeed, the monitoring device is very easy to use and fits appropriately the needs. However, it is not a continuous monitoring system and blood sample is required, which may be uncomfortable for some persons, especially children.

2.1.2 CGMS® [2]

In certain cases, the doctor often prescribes the CGMS[2], manufactured by Medtronic MiniMed, to collect accurate and continuous glucose levels. Data are analyzed to diagnostic hidden blood sugar patterns such as hypoglycemia and to evaluate the reaction after a change in the medication.

A tiny sensor is introduced under the skin of the abdomen. After insertion, the sensor is secured with tape to keep it in place. A wire connects the sensor to the monitor, generally held in the pocket. The system automatically takes measurements every five minutes during a period of three days and stores them. During this period, the patient must continue to take his glucose level with a standard system, because CGMS measurements are not calibrated; this is done off line. For this reason, no measurement is displayed.

The monitor shown in figure 2.1(b) is of size 90 x 70 x 22 mm and weighs 115 g. Data are transfered to a computer via a serial cable. A software is available for the doctor to

[1] In this report, doctor is a generic term used for all healthcare professionals
[2] CGMS: Continuous Glucose Monitoring System

manage diabetics' personal information and corresponding measurements. Batteries used are non rechargeable ones and have two months' lifetime.

The main advantage is that this low invasive device can automatically take measurements continuously for a long period of time. Nevertheless, this device can not be used for glucose level regulation.

(a) Accu-Chek Aviva (b) CGMS Gold System

Figure 2.1: commonly used monitor devices found on the Swiss market

2.2 MONITOR NEEDS

In order to identify the real needs of diabetics using such devices, it is important to discuss with concerned persons. For this purpose, a discussion has been held with a nurse[3] in diabetology from the CHUV[4]. With the help of her recommendations, a summary of the important patient's needs are listed in the next paragraphs.

2.2.1 USER INTERFACE

The main requirement is to have a system which is easy to use. Indeed, both young and elder diabetics do not know necessarily how to manipulate technical devices. The system must have a minimum number of buttons, with a user-friendly interface.

When a measurement is requested by pressing on a button, the delay for the reading to be displayed must be as short as possible.

If rechargeable batteries are used, the time between two charging must be as long as possible.

2.2.2 EXTERNAL DESIGN

The system must have more or less the same dimension and weight as a mobile telephone. It should easily fit in a pocket or carried in a bag (especially for women).

[3]Mrs. Irma Blanco
[4]CHUV: Centre Hospitalier Universitaire Vaudois

A watch format is not a good solution. In European culture, people suffering from a disease do not want that their situation is known, as it is the case in other countries like USA. Moreover, not everybody wear watches or prefer their own one, especially for women and sportsmen.

2.2.3 Display

Another important point is to have a large display with clearly visible values. Indeed, one of the complication of diabetes is angiopathy[5], resulting to a lower vision. It is also important to be able to see value during the night, so a retro-lighting is needed. Moreover, contrast must be sufficient so that readings can also be made under excessive illumination (example, in sunlight).

There are different units for glucose rate. In Switzerland, mmol/l is used in current systems and values represented in these units are meaningful to diabetics. The measurement range in mmol/l is from 0 to 30. One decimal precision is required for values under 12.

Patients are accustomed to current systems in which date and time are also displayed with measurement.

A trend indication could help the patient to anticipate his medication.

2.2.4 Measurements

Automatic measurements and storage guarantee a regular data acquisition for further analysis. A measurement every ten to fifteen minutes seems to be sufficient, but a lower frequency can fail to show rapid evolution.

The patient can also request his glucose rate up to date for his auto-regulation. However the number of acquisition per day requested by the patient could be limited to avoid a paranoia behavior.

2.2.5 Alarm

The normal glucose rate is between 4 and 8 mmol/l. If the rate is out of this range, it could be dangerous. An alarm can limit the problem in these situations. The glucose rates given above are general values, alarm level should be configurable differently for each patient.

Below the normal range, the patient must take rapid sugar. When the blood glucose level falls below 2 mmol/l, there is a risk of coma. Hypoglycemia alarm is especially important during the night or during sport.

An hyperglycemia has no instantaneous impact but is dangerous in the long run; it can generate angiopathy. Hyperglycemia is generally not detected by the patient, an alarm can reduce the risk of complications.

Generally alarm on medical devices, such as insulin pump, are audible, vibrating and visual. However, even though the patient should have the possibility to deactivate if desired, some alarms must continue to operate.

[5] disease of the blood vessels

2.2.6 Computer link

A communication with a computer is used for data transmission and analysis. The majority of current systems needs an intermediate device for data transfer, such as a docking station. This intermediate device should be avoided, direct link is preferable.

2.3 Computer interface needs

A user-friendly interface must be available on the computer to manage the communication with the device. This interface can be used by both the patient and the doctor, but only some functionalities are reserved for the doctor.

2.3.1 Patient interface

The interface should principally offer the opportunity to download and store the data and display a graphic for a day, week or month. Other information include an average (on a day, week or month basis) and score (in percent) of the time in which the patient was in, over or under the normal range.

2.3.2 Doctor interface

The doctor will certainly follow many patients, a multi-patient management should be set up. His interface should be able to communicate with different devices and store data in adequate folder.

To avoid errors from patient manipulation, erasing data stored in the monitoring device must only be made by the doctor. Thus data will not be lost between two medical appointments (time between two appointments may vary from 1 to 6 month, depending on the severeness of the diabetes).

More sophisticated data analysis tools must be available for healthcare professionals. For example, the doctor should be able to superpose weekly graphics or make statistical analysis.

2.4 Project requirements

The systems presented in sections 2.1.1 and 2.1.2 are complementary, but no single system exist. Such device, associated with the sensor developed in the LPM, would have the following characteristics:

- continuous glucose monitoring without patient intervention
- data stored in the device itself for a long period of time
- display of measurement on request for auto-regulation

The monitor requirements, based on section 2.2 are shown on table 2.1. The computer user interface must have main functionalities presented on section 2.3. They are shown on table 2.2.

MONITOR REQUIREMENTS	
User interface	
Interface	easy to use
Autonomy (min)	7 days
Acquisition time (max)	5 s
External design	
Look	attractive
Size (max)	120 x 80 x 30 mm
Weight (max)	200 g
Display	
Content	value, date, time, trend
Value dimensions (min)	20 x 10 mm
Units format	mmol/l
Precision	one decimal place
Retro-lighting	yes
Measurements	
Automatic	yes
On request	yes
Storage capacity (min)	3 months measurement at 10 minutes interval
Alarm	
Primary format	audible
Mute mode	yes
Glucose rate thresholds	configurable
Computer link	
Intermediate device	none
Wireless communication with bio-sensor	
Range (min)	3 m
RF compatibility	medical specifications

Table 2.1: monitor requirements

2.5 SUGGESTED SOLUTIONS

This section presents some interesting solutions with their advantages and disadvantages.

2.5.1 WRIST PDA®[3]

The LPM was interested in having an attractive product, such as a watch. The Wrist PDA[6] proposed, is based on Palm OS[7]; the software development is done directly on a Palm or with an emulator.

An RF interface must be developed using available interface on Wrist PDA (USB[8] or

[6]PDA: Personal Digital Assistant
[7]OS: Operating System
[8]USB: Universal Serial Bus

COMPUTER INTERFACE REQUIREMENTS	
User interface	
Interface	easy to use
Presentation	graphics with buttons
Data management	
Presentation	graphic
Storage	raw format
Export format	*.csv[a]
Monitor control	
Data download time (max)	2 min
Data erase	yes
Configuration	yes

[a]This file format is often used to exchange data between disparate applications.

Table 2.2: monitor requirements

IrDA[9]).

Advantages

- Computer software allowing data transfer via USB exists.
- Comfortable display screen: 160 x 160 pixels, 16 level grayscale, backlight and a touch screen interface.
- Attractive product for a demonstrator bench, especially with a flexible circuit in the watch bracelet.

Disadvantages

- Interface limitations:
  - Slave USB interface: communication must be established by a master device. This requires subsequent coding and only few devices can be found on a market.
  - IrDA interface: in addition to RF link, another wireless module is needed, which complicates the integration.
- Multi-target development necessary: solution requires software development for three different targets (Wrist PDA, RF interface device and computer)
- Dependency of a commercial product: the price, availability[10] and development tools of the system depend on the evolution of this product. It can be a solution for a demonstrator bench, but not for future development.

[9]IrDA: Infrared Data Association; wireless optical communication
[10]NB: On February 2006, Fossil seems to have discontinued this watch

- Low autonomy: the current Wrist PDA watch has only 3 days of power with 30 minutes of use per day.
- Watch format: for the reasons explained in section 2.2.2, it is not suitable.

2.5.2 PCMCIA [4]

A PCMCIA[11] card can be used with many devices such as notebooks and PDA. Developing this kind of card is possible.

A hardware design integrating a RF module must be done and corresponding driver must be coded.

Advantages

- Same interface with computer or PDA (a Palm or iPaq).
- Large choice of device. The development could be done on a computer or a PDA.

Disadvantages

- Multi-target development necessary.
- Dependency of a commercial product.
- Time required for writing a driver.
- Mechanical constraints for compatibility.

2.5.3 Other devices

Lots of embedded systems exist. It could be possible to adapt a MP3 player or mobile telephone for example.

Hardware and software part must be developed to integrate a RF module.

Advantages

- Large choice of device.
- Attractive look for a demonstrator bench.

Disadvantages

- Multi-target development necessary.
- High dependency of a commercial product.
- Generally developer tools not available.

[11] PCMCIA: Personal Computer Memory Card International Association

2.5.4 "Home-made" system

An other solution is to entirely develop a system. It avoids limitations from another device to match the project requirements.

Advantages

- Complete knowledge of the system, without intermediate "black boxes".
- Not dependent on a commercial device. It is better for a long term basis.
- Only two targets in software development: computer and control device.
- All mechanical parts fit in a unique enclosure.
- Only necessary components used: this allows simple optimization for longer autonomy.
- Format, autonomy could be freely chosen.

Disadvantages

- Development is longer, in case of a demonstrator bench.
- Difficult to have a small and attractive device.
- Cost of development is generally high.

2.5.5 Selected system

As seen above, the best solution is to develop entirely a new system. Indeed, a custom-made system simplifies the communication link between the sensor and the PC, as depicted in figure 2.2; all other solutions require an additional interface to communicate with the control device as shown in figure 2.3. Consequently, as there is less software development constraints in the home-made solution, this allows more flexibility for optimizations.

On the other hand, a home-made solution requires more hardware development, but this is the price to pay for developing a more efficient hardware design. Indeed, in a home-made solution it is easier to restrict components to functional requirements only, thus the system will be energetically effective.

Finally, our proposed custom-made solution will use the USB port as it is widely present in almost all PC. The control device will be referred to as **GlucoBox Control Device** and the PC software as **GlucoBox Software** – the two are part of **GlucoBox System**.

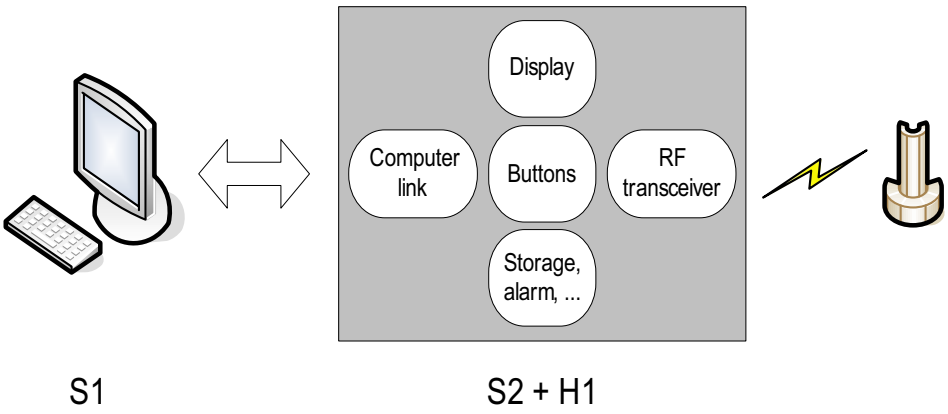

Figure 2.2: custom-made concept (Sx: software development, Hx: hardware development)

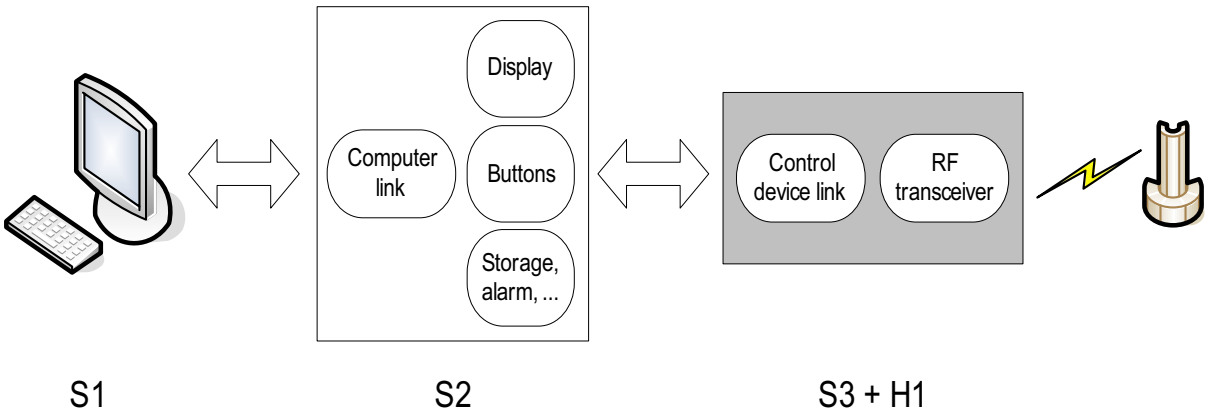

Figure 2.3: concept based on an existing host (Sx: software development, Hx: hardware development)

3 GlucoBox System

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3.1 Control device

As seen before, the important characteristics of the GlucoBox are its simplicity of use and reliability of measurement. Hence, our design takes into account these points, as we will see in details below. But first, we must note that GlucoBox will be used by both the doctor and the patient, the latter being the end user. The doctor can access advanced features of GlucoBox only by means of the computer software.

3.1.1 External aspect

The control device will be in a small form factor, near the size of modern cellular phone. The main interface of the device is composed of a large LCD[1] screen and two push buttons, as illustrated in figure 3.1. The enclosure is a molded, black, textured ABS[2] case. External dimensions are also given.

Display is also back-lighted, making it possible to read values in dark circumstances. Other information such as battery level, RF link and warnings, are also available in the form of icons in the top part of the screen.

Push buttons are large enough and require a minimum pressure to be closed; this prevents unexpected action from user when GlucoBox is placed in bag for example.

The overall weight of the device does not exceed 115 g.

[1] LCD: Liquid Crystal Display
[2] ABS: Acrylonitrile Butadiene Styrene is a common thermoplastic used to make light, rigid, molded products

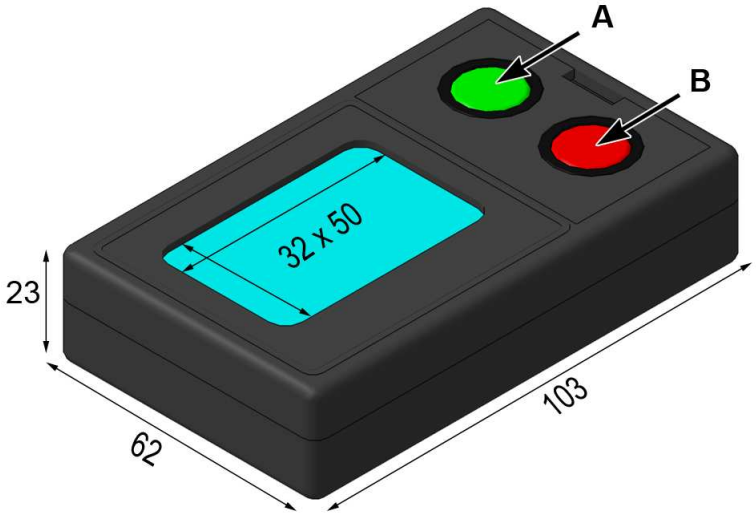

Figure 3.1: GlucoBox dimensions in mm

3.1.2 MANIPULATIONS

One of the most frequent tasks that the patient will perform is requesting an instantaneous measurement. This is simply done by pressing once on button (A) . If the sensor is within range, a value is then displayed (note that the aerial icon is activated during process). Other reactions may occur after a value has been acquired: the general trend (↑ or ↓) is shown, then according to glucose threshold alarm that has been previously set, an audible alarm may resound (the bell icon is activated by default). One can notice that this process can be scheduled to occur at regular time interval; in this case, no information is displayed except in case of an alarm.

When the USB cable is plugged into the device, the latter is automatically recognized (provided that appropriate drivers have been installed prior to connection). User can then run host application to start communicate with the control unit. For more information about functions available in software, go to next section.

The built-in battery of GlucoBox can easily be charged by two methods: energy can be taken from either an AC adapter (specifications are given in appendix A) – supplied with GlucoBox – or from the USB port. The first method is quicker.

The device is equipped with a buzzer that can emit a beep on programmed alarms. The sound level can be set or deactivated using button (B) (sound mode can be toggled by holding button for 2 s).

3.1.3 Connectivity

Common connections

On the side of the device, there are two connection ports: a mini female USB port for communication with a PC and a female DC plug. There is also a reset button (accessible with the help of a pin) and a charging indicator LED[3] (see figure 3.2).

Charging can be done by plugging-in a DC source (maximum 6 V). Polarization in not important as GlucoBox accepts either case. The device can also be charged via the USB port. For more specifications on power supply, refer to appendix A.

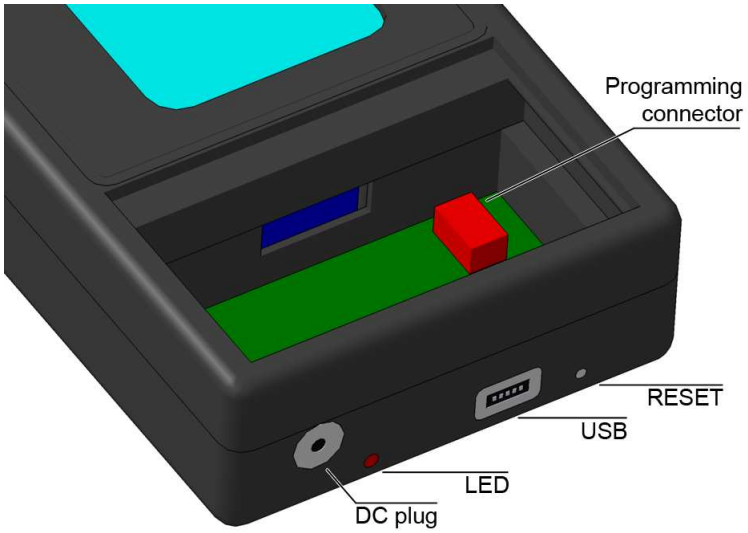

Figure 3.2: view of connectors of GlucoBox

Another important link is the RF wireless connection. With its built-in antenna, GlucoBox is able to communicate with the remote sensor.

Programming interface

The control device possesses also a special connector to be used for **firmware upgrade**. Indeed, this special port, accessible by removing the front lid (see appendix C.2 for more details), allows technical user to upload firmware by using an appropriate programmer. The figure 3.3 gives the pinning of the port in details.

[3]LED: Light Emitting Diode

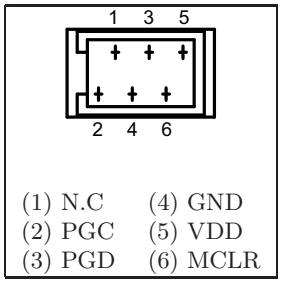

Figure 3.3: details of programming connector

3.2 COMPUTER INTERFACE

The GlucoBox program communicates with the control device to download data stored in it. A graphic shows the evolution of the glucose rate during the acquisition period. The software gives also the possibility to set up some parameters of the GlucoBox.

3.2.1 RUNNING THE INTERFACE

The interface is an self-executable running on Windows. The required specifications for using this application are presented in the appendix B. Before launching this application, the GlucoBox must be connected via USB, or else an error dialog box will appear.

3.2.2 USING THE INTERFACE

The interface shown in figure 3.4 contains four tabs:

- User: The user sees the time and date of the GlucoBox, can manage data (acquisition, storage and erasing) and change parameters (date and time, alarm volume, automatic acquisition frequency and alarm glucose level).
- Config: It is necessary to configure the communication (COM port selection and baud rate choose) before to initiate it. The path for data storage can also be fixed.
- Display: A graphic is proposed to show the glucose level evolution. The user can choose to display either the current acquired data, or import data previously acquired.
- Debug: This tab is reserved for developers only.

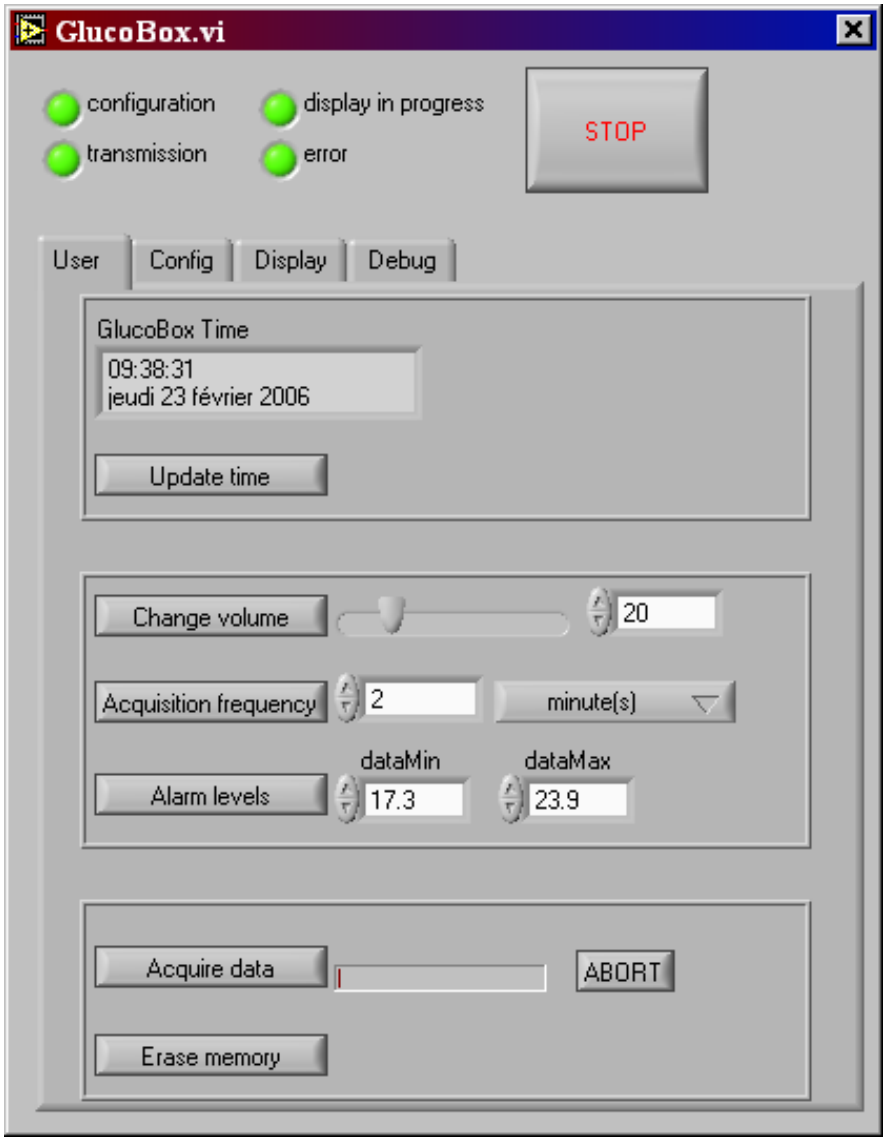

Figure 3.4: graphical interface

4 Control device

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In order to achieve the functional requirements of the control unit, the corresponding components for each task need to be wisely selected. A wide range of components exists, but our selection is based on two main criteria: size and availability. The main reason is that these criteria allow us to rapidly validate our concept. Although these parts may not necessarily be the optimal ones, they shall fit in our demonstrator application. The next paragraphs depict in details the characteristics of each part.

4.1 ARCHITECTURE

One of the important factors when choosing an architecture is to decide which MCU[1] is the most suitable. On the market, there are a large number of MCU, some are dedicated or optimized for special task. After the MCU has been selected, the peripherals[2] – in the form of an IC[3] – must be chosen according to type of interface available on the MCU.

For the MCU, the dsPIC30F4011 [5] has been chosen for several reasons:

- It is readily available.
- It exists in small package form.
- This MCU is commonly used in the LPM laboratory (in fact, the actual bio-sensor is built with this MCU !) and hence all hardware and software tools are immediately available; another non-negligible aspect is that, at the LPM, there is a good background on this MCU.
- By using the same MCU as in the bio-sensor, code portability and integration are easier.
- The MCU has enough IO[4] lines and modules[5] required in our application.

Another important feature of the dsPIC30F4011 is that it incorporates an internal oscillator: the latter can be configured to deliver sufficient computing power with a good comprise on power consumption. Furthermore, it can operate at 3.3 V, which is a common voltage for low power devices.

The next step is to choose the peripherals compatible with the MCU and 3.3 V. Moreover, the SPI[6] has been chosen as interface with the peripherals for its ease of use and its performance.

In order to achieve functional requirements of our project, the following peripherals are necessary:

- a display with back-light,
- a time-management circuit to assign time stamp to each measurement and to allow scheduling of readings,
- a non-volatile memory to store measured values (with a time stamp),
- a USB to UART[7] transceiver to allow communication between the MCU and a PC via USB.

[1] MCU: Main Control Unit; in our case, it is a micro-controller
[2] special device that is generally dedicated to a special task, for example, a non-volatile memory
[3] IC: Integrated Circuit
[4] IO: Input/Output
[5] a special dedicated part of the MCU which accomplishes a special task, for example, the UART module
[6] SPI: Serial Peripheral Interface; a trademark of Motorola, Inc.
[7] UART: Universal Asynchronous Receiver Transmitter

In addition to peripherals, power supply circuits must chosen to meet power requirements of all components. Finally, the architecture is illustrated in figure 4.1. Each component is discussed in the next paragraphs.

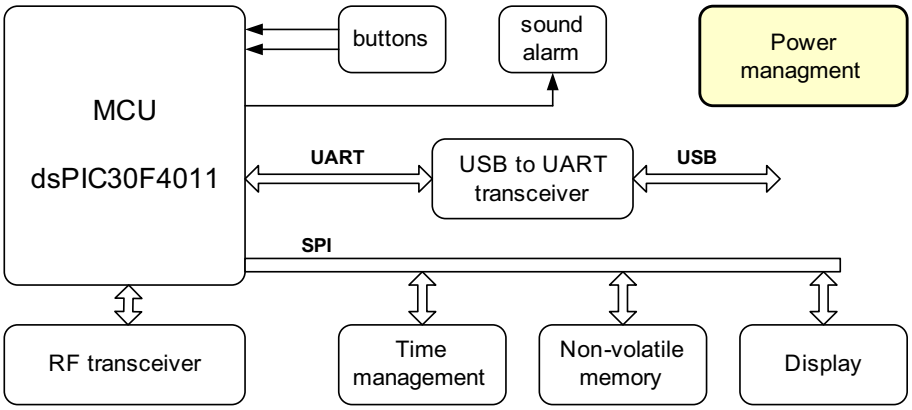


Figure 4.1: hardware architecture of GlucoBox Control Device

4.2 EMBEDDED PERIPHERALS

In this section, the characteristics, the hardware and software integration of the specific IC are explained.

4.2.1 NON-VOLATILE MEMORY

The data must be stored in a non-volatile memory to avoid loosing them in case of power loss. The size of this memory must be at least 150 kbytes, according to following equations.

$$\begin{aligned} \text{memory size} &= (\text{data size}) \times (\text{number of data}) \\ \text{data size} &= (\text{timeStamp size}) + (\text{measurement size}) \\ \text{number of data} &= (\text{acquisition period}) \times (\text{acquisition frequency}) \end{aligned}$$

with

$$\begin{aligned} \text{timeStamp size} &= 7 \text{ bytes}^{8} \\ \text{measurement size} &= 4 \text{ bytes} \\ \text{acquisition period} &= 3 \text{ months} = 90 \text{ days} \\ \text{acquisition frequency} &= 6 \text{ per hour} = 144 \text{ per day} \\ \Rightarrow \text{memory size} &= (7+4) \times (90 \times 144) = \underline{142560 \text{ bytes}} \end{aligned}$$

[8] 1 byte for each: hour, minute, second, day, date, month, year

The space required cannot fit into the MCU user memory (type is usually EEPROM[9]). Hence, an external memory with sufficient capacity is required. A serial flash-memory has been chosen as it requires few IO lines and it has a tiny package form. It fits all the requirements and standard models available have large capacities, allowing longer acquisition periods. The characteristics of the IC used are listed in table 4.1.

NON-VOLATILE MEMORY	
Reference	M45PE80VMP [6] from ST
Type	Flash
Memory size	1 Mbyte (8 Mbits)
Interface	SPI
Voltage	2.7 to 3.6 V
Standby current	50 μA
Packaging	VDFPN8
Dimensions	6 x 5 mm

Table 4.1: flash-memory characteristics

HARDWARE

Electrical connections required is quite simple, as shown in appendix E.3.

SOFTWARE

The memory is organized in 16 sectors, each containing 256 pages which are 256 bytes-wide. In current use, the first sector is reserved for GlucoBox special parameters. These values are loaded after a reset. The rest of the memory (15 sectors) can handle up to 85'000 measurements (including time stamp) in the current implementation.

Modifying data can be done by two ways:

- Write data: It is the more usual way to modify data. The PW[10] instruction provides a convenient way of modifying data and simply requires the start address and the new data in the instruction sequence. This instruction takes typically 11 ms.
- Program data: The PP[11] instruction provides a fast (typically 1.2 ms) way of modifying data, provided that it only involves resetting bits to 0 that had previously been set to 1 (after a PE[12] instruction for example).

In current implementation, a total erasing (with PE instructions) is done before that the measurements are stored. This erasing ensures that no overwriting occurs and that all bits are set to 1. It provides the use of PP for measurements storage, which is faster than PW.

[9] EEPROM: Electrically Erasable Read Only Memory
[10] PW: Page Write
[11] PP: Page Program
[12] PE: Page Erase

However, PW is used for the special parameters (first sector), because these data are continuously overwritten without PE instruction being done between two PW instructions.

It is important to note that if memory is full, all subsequent storage of readings is ignored. In this case, patient is informed by an icon on the display.

4.2.2 USB TRANSCEIVER

As the chosen MCU does not have a USB module, an external transceiver in needed to communicate with a PC. For this purpose, specialized IC are available on the market, the most common of them is the FT232B [7] from FTDI. The main advantages of using this IC is its maturity and the complete software support from the manufacturer. The connection on the host PC can be implemented in two ways: as a serial communication port or a normal USB port (both drivers are available for different OS). The first method is simpler for the software development on the host PC. Moreover, a high transfer rate is not necessary for our application. The characteristics of the FT232B are summarized in table 4.2.

USB TO UART TRANSCEIVER	
Reference	FT232BQ
Interface	UART & USB
IO voltage	3.0 to 3.6 V
Suspend current	200 μA
Package	QFN32
Dimensions	5 x 5 mm

Table 4.2: USB transceiver characteristics

HARDWARE

No particular components are required to use the FT232B (refer to appendix E.6), except that care must be taken regarding to the precision of the crystal (see datasheet for more details). An interesting feature of the FT232B is that it can be powered from the USB cable, thus the IC operates only a USB connection is present. This simplify power saving scheme implementation.

SOFTWARE

As mentioned before, the FT232B is used a serial communication port[13] on the host PC. Hence, the FT232B is transparent to the communication between MCU and host PC. Indeed, for the PC, the MCU is a simple data terminal equipment. On the other hand, the MCU can communicate directly to the PC by simply sending data using its UART module.

[13] in fact, this port is a virtual port as host program thinks it is a usual communication port; this abstraction from the real port is provided by installed drivers

4.2.3 TIME MANAGEMENT

The date and time must be known for time stamping measurements and for patient general information. A software implementation on the MCU can be done, but it will constantly need processor resources, preventing the MCU to enter power saving mode. A more efficient way to save energy is to use an external device for time-keeping (it usually consumes much less energy than the MCU; this is the role of a RTC [14]. In our application, a RTC with its own power management is required. Nowadays, this criterion is commonly implemented. However, more features like programmable wake up, electrical interface, size and availability restricted our choice. The DS1305 [8] from MAXIM has been chosen for its characteristics, namely those shown in table 4.3.

RTC	
Reference	DS1305E
Interface	SPI
Time resolution	seconds
Power management	auto-select from primary or backup source
Voltage	2.0 to 5.5 V
Timekeeping current	1 μA
Package	TSSOP-20
Dimensions	6.4 x 4.4 mm

Table 4.3: RTC characteristics

HARDWARE

This IC needs a precise 32.768 kHz crystal (refer to datasheet for more information). The RTC will use primary source to power itself (GlucoBox being generally powered at all time). Nevertheless, in case on main power loss, a backup battery, in the form of a large value capacitor (0.2 F) is required to keep the RTC working. This type of source is very compact and can provide sufficient energy for about a week, according to equation 4.1, which is sufficient for our application. Calculations are based on [9]. Electrical implementation is provided in appendix E.3.

$$\begin{aligned} \text{time} &= -\ln\left(\frac{V_{backup|min}}{V_{backup|max}}\right) \times \frac{V_{backup|min}}{I_{backup|max}} \times \text{Capacitor} \\ &= -\ln\left(\frac{1.3}{3.3}\right) \times \frac{3.3}{10^{-6}} \times 0.2 \\ &\approx 600'000\,\text{s} \approx 167\,\text{h} \approx 7\,\text{days} \end{aligned} \tag{4.1}$$

SOFTWARE

The RTC can be configured by accessing special registers in the IC via the SPI interface. To setup up the RTC, the following steps are made:

[14] RTC: real-time clock

- When the RTC is powered to the first time, the oscillator is locked. The oscillator will run after the control register has been correctly written to.
- Enable alarm by writing to the status register.
- Configure the super capacitor charge by writing in the trickle charger register.

Time information can be read at any time in the corresponding registers of the RTC. The format used is specific and is not suitable as a time stamp. A function that converts to readable format has been implemented. The time stamp is then represented by a set of 7 bytes containing corresponding values of year, month, day, date, hour, minute and second.

4.2.4 Display

The measurement must be displayed on a screen to inform the patient of his glucose level. A large dot-matrix LCD[15] module (including driver) has been chosen, to allow further enhancements (glucose level trend on a graphic on GlucoBox). Its characteristics are shown in table 4.4. For integration of the backlight, the IC named SP4422A from SIPEX[16] has been withdrawn from its based module PSEL-22 [10] provided by Electronic Assembly and placed directly on the hardware design. For more details, refer to appendix E.4

DISPLAY	
Display reference	W128A-6X9HEW [11] from Electronic Assembly
Driver reference	S6B1713 [12] from Samsung Electonics
Interface	SPI or parallel
Resolution	128 x 64 pixels
Display size	52 x 33.5 mm
Voltage	2.4 to 3.6 V
Sleep current	100 μA

Table 4.4: graphical LCD module characteristics

Displaying a picture

The main drawback of graphical display is that displaying a text is not easy. As a matter of fact, the characters are represented by pictures and each bit of the picture must be correctly located on the screen. The data displayed are transfered from the MCU to the DDRAM[17] of the display driver via the SPI interface. The data are mapped in a 65-row by 132-column array, addressable via page and column selection (for more details, refer to the datasheet).

To load picture into the DDRAM, see appendix F.

[15] LCD: Liquid Cristal Display
[16] `http://www.sipex.com`
[17] DDRAM: Display Data Random Access Memory

4.2.5 Alarm

An audio transducer has been chosen for audible alarm. Its electrical consumption is lower than a buzzer. Moreover, by using the MCU PWM[18] module it is possible to modulate the signal (volume and frequency).

ALARM	
Reference	PKM13EPY-4000-A0 [13] from Murata
Sound pressure level (min)	70 dB
Voltage (max)	30 Vp-p

Table 4.5: piezo-ceramic alarm characteristics

4.3 Wireless communication

The wireless link between the GlucoBox and the sensor is done with a RF IC. Many IC's are available on the market, but only some of them can operate in the 433 MHZ ISM [14] (Industrial Scientific and Medical) band. Moreover, IC for medical applications such as active implants, should comply with special regulations[19] and manufacturers are less willing to face lawsuit in case of device incompatibility or failure.

An implementation of a RF chip has been done during a summer semester project citeremy at LPM laboratory. At the end of this project, an IC has been chosen by taking into account different important parameters (refer to the project report for more details) and a PCB[20] has been realized. Although it does not fully comply to the medical implant regulations, the IC has been chosen as its operating frequency is close to that required for medical implant. Indeed, for a demonstrator (an implant has not yet been developed), this prerequisite is not absolute.

At the end of this semester project, only basic electrical tests were realized but no software implementation had been done. The next step to this work is to implement the software necessary to use the RF chip. Before entering the software part, we must consider basic information of the RF chip.

4.3.1 MICRF506 overview

The MICRF506 [15] from MICREL is a true single-chip frequency shift keying transceiver intended for use in half-duplex, bidirectional RF links. It operates in the ISM frequency band of 410 - 450 MHz at a maximum data rate of 200 kbps[21]. The chip is programmed via a three-wire serial interface. Features include transmit power selection, low energy modes and RSSI[22].

[18] PWM: Power Width Modulation

[19] 402-405 MHz frequency band; ITU-T Recommendation SA 1346, US FCC rules CFR47 Part 95.628 and Europe's ETSI Standard EN301839

[20] PCB: Printed Circuit Board

[21] kbps: kilo bits per second

[22] RSSI: Received Signal Strength Indicator

The design of this transceiver is based on the reference design supplied by MICREL. General configuration of the MICRF506 in our application is summarized below:

- 433 MHz operating frequency
- VCO modulation at 38.462 kbps
- Manchester encoding [23]
- RSSI enabled

Manchester encoding [16] has been used as it does not add much overhead. This type of coding is recommended by MICREL but other types of coding may also be used.

Interface with MICRF506 is done with the help of 8 lines, as shown in figure 4.2. Description of each line is given below.

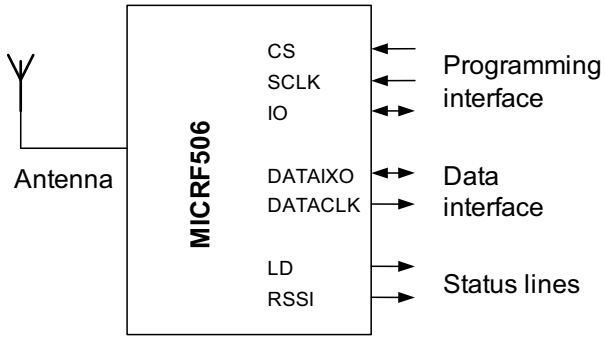


Figure 4.2: electrical interface of MICRF506

Programming interface. The MICRF506 functions are enabled through a number of programming bits. The programming bits are organized as s set of addressable control registers, each register holding 8 bits. The control registers are accessed through a 3-wire interface; clock (input), data (bi-directional) and chip select (input). These lines are referred to as SCLK, IO and CS, respectively.

Data interface. The data interface consists of a clock (output as it is provided by MICRF506) and a bi-directional data. These lines are referred to as DATACLK and DATAIXO, respectively. The data interface is defined in such a way that all user action should take place on falling edge of DATACLK.

Other lines. Two more lines (outputs) are provided more information about the IC: a lock-detect pin (LD) indicates that the PLL[24] is locked and a RSSI analog pin gives the strength of the RF signal.

[23] 0 is represented by a 0↑1 transition and 1 by a 1↓0 transition
[24] PLL: phase lock-loop, more details in datasheet

Antenna. Through this essential component, the transceiver will emit and receive RF signals. Main characteristics are impedance and gain. Antenna can be found in various forms, each with its advantages and drawbacks. Making antennas is itself a field of study. In our application, antenna performance is not critical (a range of only a few meters are required). However, antenna dimension is the main factor to chose the right one. In this context, a compact SMD[25] multilayer ceramic antenna has been chosen [17].

An important note is that MICRF506 works at 2.5 V where as the MCU operates at 3.3 V. Hence, levels must be adequately translated to enable correct electrical interface between these two parts. This is done by specialized circuits exist which allow bi-directional communication. An example of such circuits is the MAX3001E [18] from MAXIM.

For more details of electrical implementation, refer to appendix E.5.

4.3.2 Implementation of a RF protocol

Data exchange through MICRF506 is done using a bidirectional data line. A RF protocol needs to be built in order to give a meaning to data other than a series of bits. For this purpose, a multilayer protocol has been developed. Figure 4.3 depicts the different layers that compose the RF protocol.

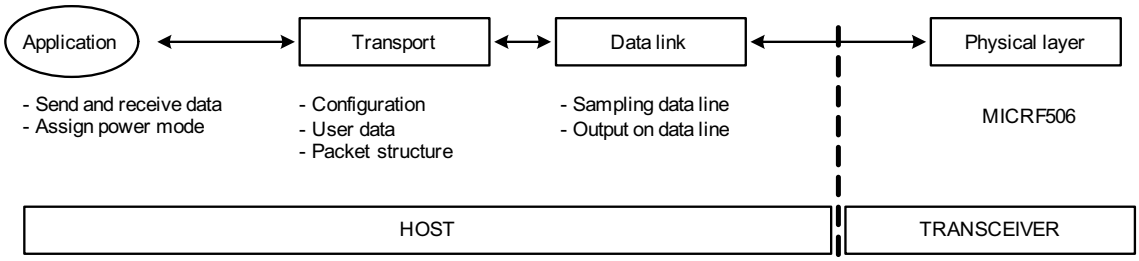


Figure 4.3: description of protocol for MICRF506

In the host part contains two layers: the **Data link** is responsible for interfacing with the MICRF506 via dedicated electrical lines and the **Transport** layer handles data at a higher level. Indeed, this layer is an essential part of the protocol as it ensures correct translation of low level data and hands it over to user application. Furthermore, the **Transport** layer provides primitives to access the transceiver. Finally, in the user application, several routines are available to easily exchange data over RF and control running state of the transceiver.

This implementation is quite common to a wide range of protocols. Indeed, protocols are structured in layers in order to give higher level of abstraction on upper layers. Each layer can be considered as a black-box with inputs and outputs. If a black-box must be modified, it does not affect upper nor lower layers (it is obvious that inputs and outputs must not be altered). A typical example is the **Data link** which is implemented according to the transceiver and host employed; if another transceiver is used, only the **Data link** is to be reprogrammed.

[25]SMD: Surface Mounted Device

FRAME STRUCTURE

Packets sent over RF are divided into blocks, as shown in figure 4.4. In our case, a maximum of 20 bytes are sent per packet (in reality, due to Manchester encoding overhead, twice that number of bytes are sent). The roles of each block are explained below.

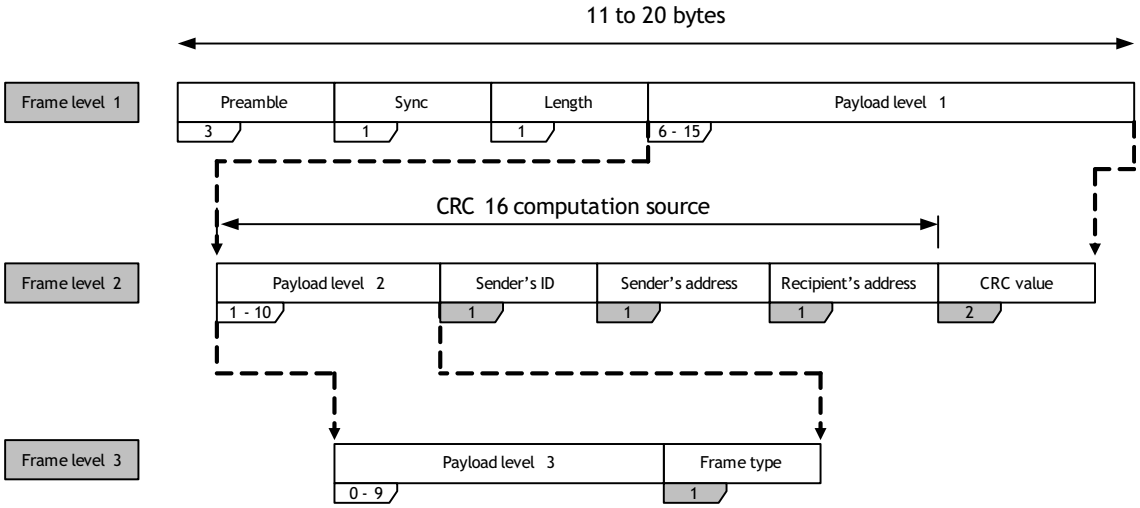


Figure 4.4: structure of the frame – values indicate size in bytes

Preamble. At the beginning of a received data packet, the bit synchronizer clock frequency is not synchronized to the bit rate. The equivalent time of a minimum number of 22 bits are required before synchronization is achieved. In our application, more bits are used so that receiver in search mode can sample correctly RSSI level.

Sync. Data received is merely a bit stream without start nor end parts. This byte allows receiver to identify where is the start of the packet.

Length. This byte is necessary to inform receiver how many bits is expected in the packet. The value must be in the allowed range of frame structure (6 to 15) or else, rest of packet is ignored.

Sender's ID and Address. The sender has two parameters which help to identify it. Its identification (ID) is a value that represents the class of equipment to which it belongs (at this stage only one ID is used, other values will be allocated in the future) and its address must be unique in each class of equipment. Receiver is programmed to respond to only a specific class ID and to one sender (address) at a time.

Recipient's Address. This value is verified by receiver to check to whom the packet is intended. In this case of address match with its own address, receiver will undertake action.

CRC Value. Integrity of packet must be verified to ensure that data it contains are correct. A CRC[26] computation is a common way to validate data integrity. Implementation used is based on the CCITT[27] algorithm. The 16-bit version is used [19]. More information can be found on the Internet, a good start is [20].

Frame type. The final payload extracted is called *Payload Level 2*. It includes a field that designates the type of the frame. It allows custom commands to be simply implemented here and extra data can be put in the rest of the payload (*Payload Level 3*).

In our case, the values given are sufficient to realize required tasks in a **Master − Slave** configuration (the master being the GlucoBox and the slave is the remote sensor). The size of each part can be easily modified to fit other applications. Moreover, the frame structure provides a flexible framework to implement more complex networks (multi-master, routing, broadcasting, etc.).

4.3.3 Software implementation

The main idea of the software implementation is to make usage simple to programmer. Indeed, only few routines are required to immediately use the RF communication. The trade-off is that some part can only be set at firmware level (for more details, refer to appendix G). Figure 4.5 shows how to proceed in main program.

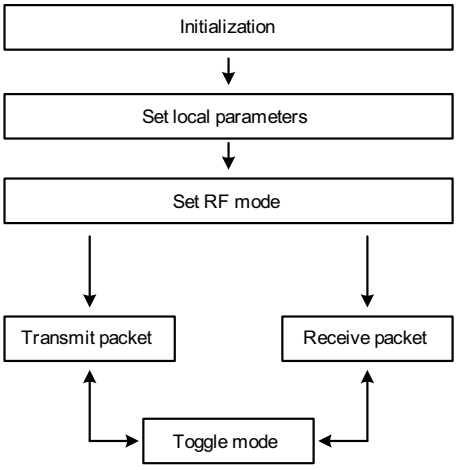


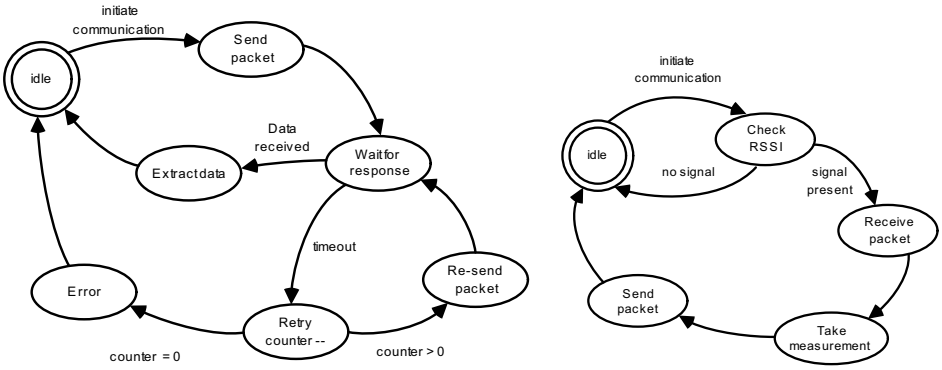
Figure 4.5: only few steps are required to use RF protocol

A typical scheme on application is given in figure 4.6. In this example, figure 4.6(a) represents the master (GlucoBox) while figure 4.6(b) corresponds to the slave (sensor). Using different power states, it is possible to implement a low energy consuming application. For example, RF IC can be automatically put in standby mode after a transmission of a reception.

For more information on how to use these routines along with code examples, see appendix G.

[26]CRC: Cyclic Redundancy Check

[27]CCITT: Comité Consultatif International Téléphonique et Télégraphique, now known as the International Telecommunication Union



(a) master state machine (b) slave state machine

Figure 4.6: examples of use of RF protocol

4.4 Power supply

The power scheme (figure 4.7) can be divided into three items: portable electrical accumulator, power supply regulation and power manager for external electrical energy source.

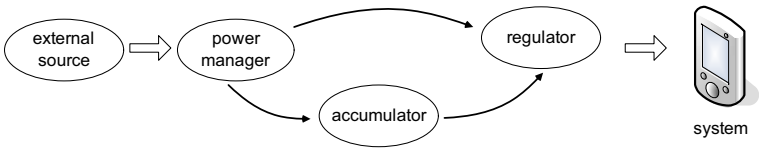


Figure 4.7: energy flow in the device

4.4.1 Accumulator

A Lithium-polymer type battery has been chosen to provide sufficient energy to our system. This type of battery has superior capacity compared to other types of batteries with same size and weight. Moreover, it can easily be found in compact slim form. The model used is for our system is a 1500 mAh running at 3.7 V from Kokam [21]. It fits our enclosure and has sufficient capacity to power our system for a minimum period of time.

4.4.2 Voltage regulator

Our system requires two different voltages: 2.5 V for RF chip and 3.3 V for the rest. Moreover, these voltages will be provided from the battery which is only at nominal 3.7 V. Hence a low-dropout regulator is necessary. An IC from Maxim [22] has all needed characteristics: in a single compact package, the MAX8883 can deliver up to 160 mA on each voltage channel.

4.4.3 Power management

A dedicated IC exists that matches exactly our needs: it's the bq24022 from Texas Instruments [23]. It has the capability of handling two sources for charging Lithium-polymer batteries (or

Lithium-Ion). Indeed, it can automatically select the USB port or the AC adapter as the power source for the system. In the USB configuration, the host can select from two preset charge rates of 100 mA and 500 mA. In the AC adapter configuration, an external resistor sets the magnitude of the charge current. This IC has been chosen for its functionalities, compactness and simplicity of implementation.

When using the bq24022, a suitable external AC adapter is a 6 V with a minimum of 1 A output. In our case, current drained from USB port has been limited to 100 mA.

4.5 EMBEDDED SOFTWARE

The software embedded on the GlucoBox has been programmed in C language and compiled with a dsPIC version of gcc: C30 (see appendix C.1). The MPLAB IDE v7.22 has been used for its development. Source code files are available on installation CD, see appendix H.

4.5.1 MAIN

The main function has two parts, they are shown in figure 4.8.

1. initialization: calls different initialization functions
2. infinite loop: calls four tasks sequentially

The user, storage and display return a value corresponding to its state (*active* or *inactive*). This information is used by the energy task to manage power.

The current implementation allows a reboot (intentional or not) without much problem. This is achieved by saving critical parameters (alarm scheduling, next storage address,...) on the non volatile flash memory. Hence, even if the MCU is reseted, these parameters can be loaded at any time. If an unexpected problem occurs, the user can simply reboot (reset pin-hole) the control device to restore the system's configuration.

4.5.2 USER TASK

The user task establishes the communication with the computer via the USB transceiver. If there is a data transaction, an interrupt occurs and the command is executed. The command with its data is received from the computer and the corresponding command is executed. The principal components of this function are shown in figure 4.9. The different commands will be explained in the chapter 5 (which describes the PC software).

4.5.3 STORAGE TASK

The storage task is responsible for automatically acquiring measurement and storage. Most of the time, the MCU is in sleep mode and is waked up by the RTC alarm; this triggers a communication with the sensor and fetch data. The figure 4.10 shows this task in details.

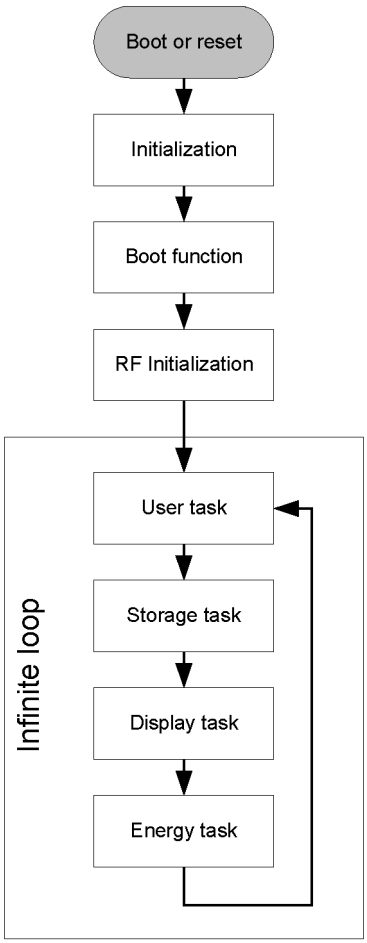


Figure 4.8: global scheme

4.5.4 Display task

The display task, presented in figure 4.11, is responsible for the user interaction: display is requested through the two buttons. The green button is used to display a measurement and the red one for enabling/disabling the audible alarm.

4.5.5 Energy task

The energy task manages power consumption of the control device. If the latter is in idle mode, external devices are put in energy saving mode and the MCU enters sleep mode. Any interrupt can then wake up the MCU. Only then, the other peripherals are waked up if necessary. This procedure is shown in figure 4.12.

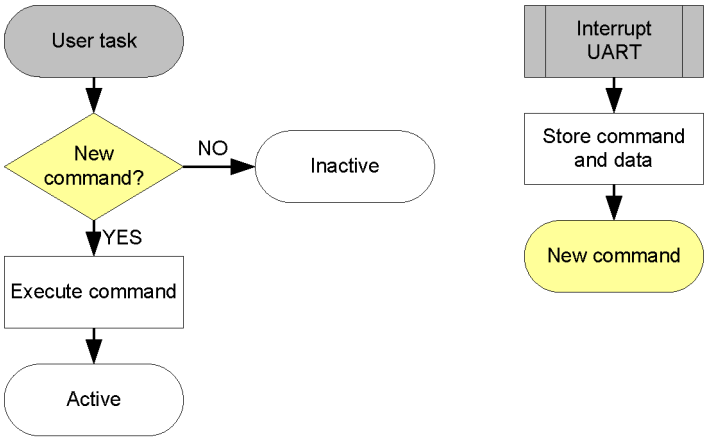


Figure 4.9: user task

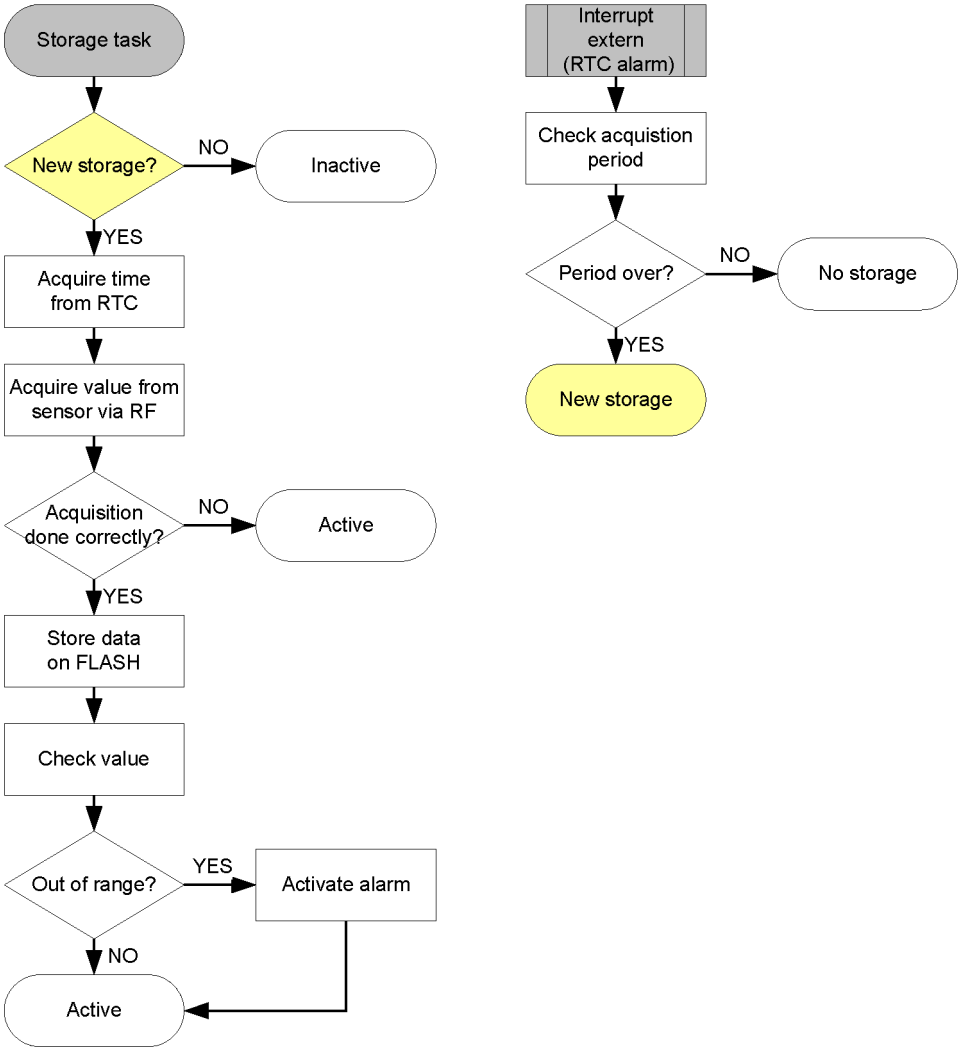


Figure 4.10: storage task

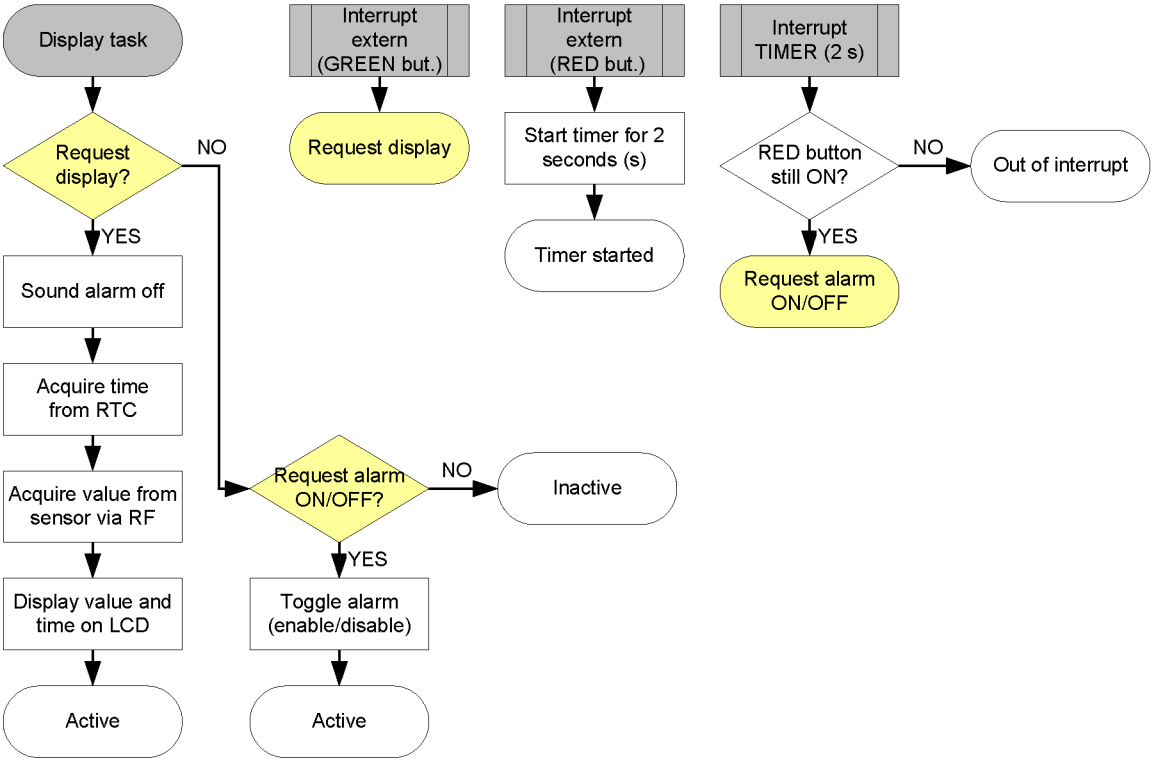


Figure 4.11: display task

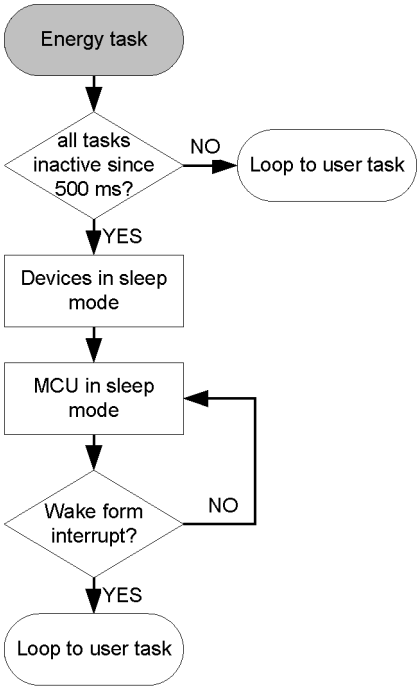


Figure 4.12: energy task

5 SOFTWARE

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5.2 Functionalities 36
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5.2.2 User tab 37
5.2.3 Display tab 38
5.2.4 Debug tab 38

The GlucoBox software running on the computer is a graphical user interface giving the possibility to manage data (acquisition, storage, graphic display and export) and parameters from the Glucobox. The goal of this software is to quickly show the capability of the control device.

5.1 PROGRAMMING ENVIRONMENT: LABVIEW

Labview®[1] has been chosen as it allows rapid development of complex program. It contains a lot of functions for data acquisition, file management and other useful features. Indeed, Labview has built-in serial functions, which allow easy communication with the serial device. The final application has an attractive visual interface.

5.2 FUNCTIONALITIES

The functionalities are available for the user through four tabs with different usage. Four LEDs give information about the state of the program, they are described below in corresponding sections. The main components of the program are shown in figure 5.1.

5.2.1 CONFIG TAB

This fields of this tab, shown in figure 5.2, must be filled in correctly before beginning the communication with the GlucoBox control device:

1. The correct port, through which the control device is connected must be selected (generally noted as ASRLX::INSTR, where X corresponds to the number of the COM port; please refer to appendix B.7.2 for driver installation).

[1]This product from National Instrument (`http://www.ni.com/`) is a graphical programming environment to build data acquisition and instrument control applications.

2. The baudrate correspond to the connection speed. It can be changed by the user but must be compatible with the configuration of the MCU. On current implementation, the chosen baudrate is 476 kbits per second.

3. The program gather data and store them in the user-defined save path. This path must be valid prior to saving data.

After all theses fields have been correctly filled in, the configuration button must be activated, and only then functionalities may be used. The *configuration* LED toggles from red to green to confirm that the configuration has been done. The configuration parameters are fixed as long as the program is running. To change parameters, the user must first stop the application with the corresponding button.

The transmission enable check must be set for data transfer; the corresponding LED shows its state. In case of communication failure, this check can be disabled then re-enabled, to restore the communication.

5.2.2 User tab

When the configuration is done and the transmission enable, the user can interact with the control device. The interaction This tab contains three parts, shown in figure 5.3:

1. Time management: If no other functionality is used, the program automatically request the GlucoBox date and time every 100 ms. The user can also update the time if it is wrong (due to too long inactivity period for example).

2. Parameters setting: The acquisition frequency, alarm volume and the two glucose level thresholds can be set separately.

3. Data management: The data acquired by the GlucoBox can be download and stored in the computer. The download time depends of the volume of data to transfer, a progress bar informs the user of the transfer state. An abort button is also available. All the data stored in the GlucoBox can be erased if the corresponding button is activated.

The raw data acquired are saved with the date as name (example 23-02-06.gbx). Note that the *.gbx extension has been created for this application. Data are simply 8-bits values.

Example: time update procedure

All commands are implemented in the same way. An example of the time update command is described below. The figure 5.4 shows how this command is implemented in Labview.

1. The user activates the update time button.

2. Labview sends the corresponding command (1 byte) with the date and time (7 bytes) via the serial port.

3. The GlucoBox MCU receives the command through its interruption routine. The MCU interprets this command and excepts 7 more bytes data. When all the bytes have been received, it stores them in a buffer.

4. The MCU executes the corresponding part of user task: reads the buffer, converts date and time to RTC compatible format and write them to the RTC.

5.2.3 Display tab

In this tab, a graphic shows the glucose level evolutions. The development of this XY display is relatively easy thanks to Labview built-in plot modules. Some tools are available for the user, to manage the graphic (zooming, moving, ...).

In current implementation, when the display button is activated, a export file is automatically created. This *.csv file (example 23-02-06.csv), containing the data in a adequate format, can be directly opened in Excel for further analysis.

Displaying the graphic may take some time, depending on the number of data; during this period, the communication is lost: the *display in progress* LED turns red. The figure 5.5 represents three screenshots of the display: initial view, with a plot of acquired data and a zoom on a special zone.

5.2.4 Debug tab

This tab, shown in figure 5.6, is intended to developers only and is used to test and validate new commands between the computer software and the control device. The command are sent as the same way as commands available in the user tab. Data received from the MCU are displayed in different format (byte array, string, boolean array).

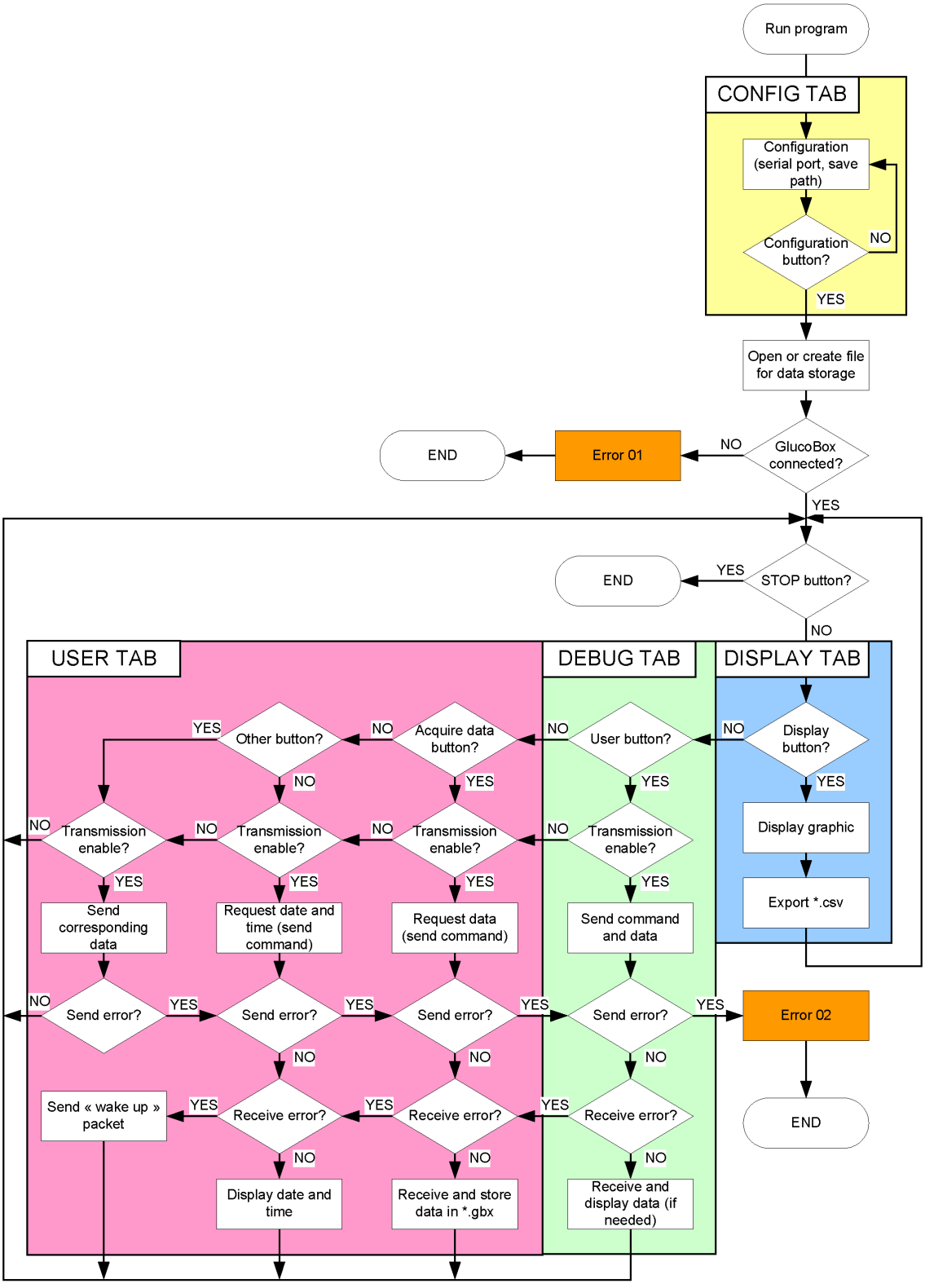


Figure 5.1: flowchart of GlucoBox Software

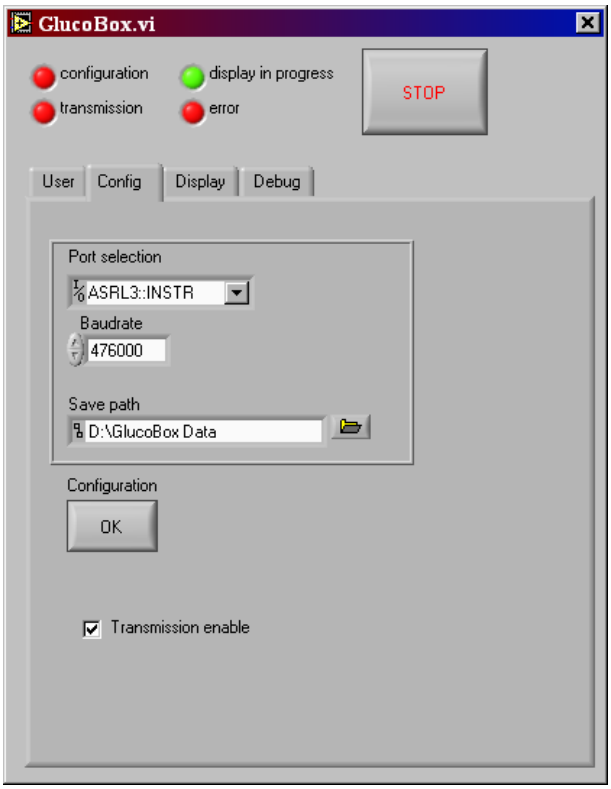


Figure 5.2: configuration

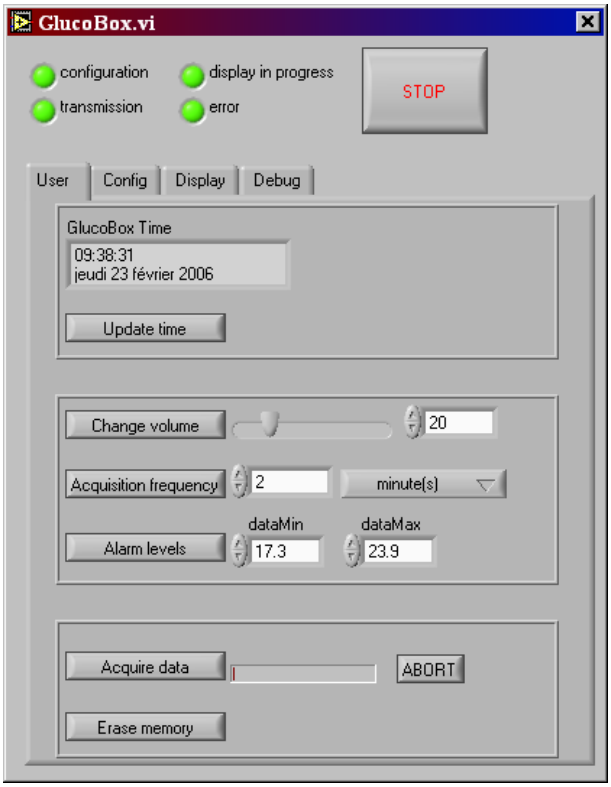


Figure 5.3: interaction with the GlucoBox

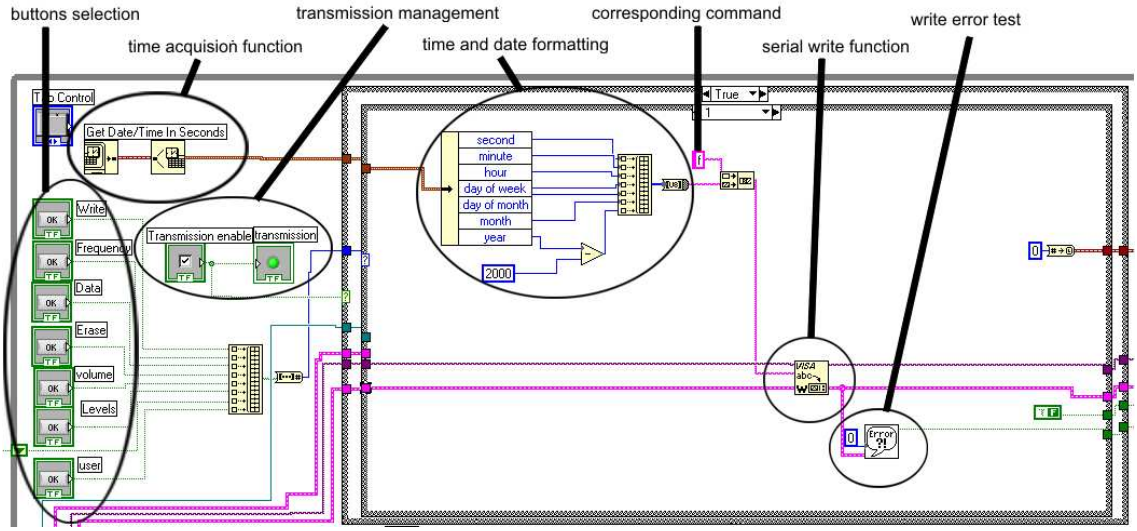
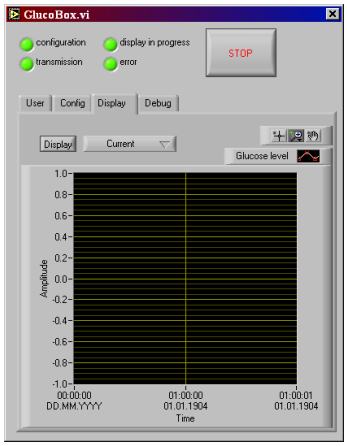
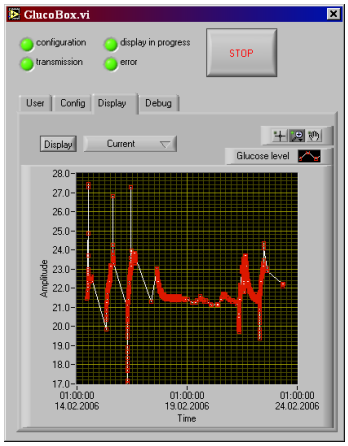


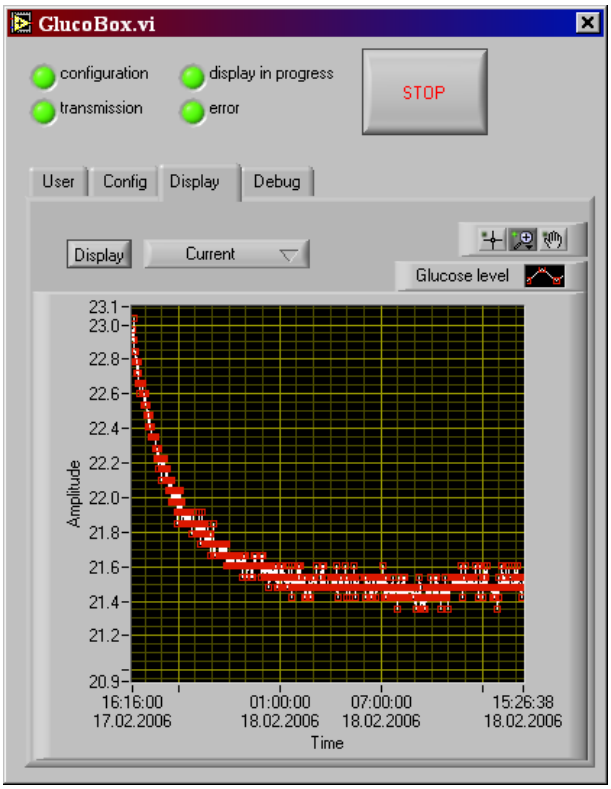
Figure 5.4: example of Labview implementation of the *time update* command



(a) before plot



(b) after plot



(c) after zooming

Figure 5.5: graphic display steps

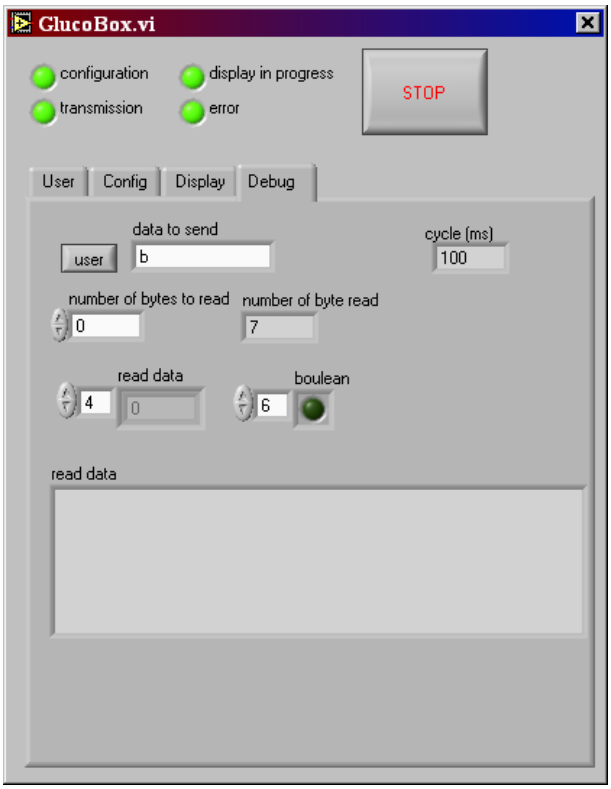


Figure 5.6: developer's tab

6 HARDWARE DESIGN

Contents

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6.2 PCB layout 44

Once all the components have been selected, the design can start. There are two main aspects:

- **Mechanical**. Main constraints are placement of components which are visible from outside of the case. In doing so, the size and the form the PCB will be defined.
- **Electrical**. Once the dimensions of the PCB are defined, the layout of all electrical components can be made.

It can be noted that the first part can be refined if additional constraints are revealed in the second part. For this reason, this approach is not strict and backward re-definitions may be necessary.

6.1 MECHANICAL

A common ABS plastic case has been chosen to contain all components. We have taken advantage of the presence of the battery room to fit all necessary connections, namely the programming connector. Hence, the latter can be easily accessed by simply removing the lid. Figure 6.1 shows in details on how all the mechanical parts are assembled in the GlucoBox. However, this accommodation of the connectors imposed the use of two separate PCB (referred to as **main board** and **daughter board**). Each of them was defined by the maximum place available in the assemblage and are interconnected through a multi-way flat cable.

6.2 PCB LAYOUT

Before designing a PCB, it is obvious that all necessary components should be known. For this purpose, each device has been tested on prototype boards to evaluate them. Then, all values of each component were assigned.

The first step when designing a PCB is to know which technology will be used. In our case, standard rigid epoxy board, 0.8mm thick for two layers has been chosen. The main reasons for this choice is that the PCB can be realized quickly (at ACI workshop[1] of the EPFL)

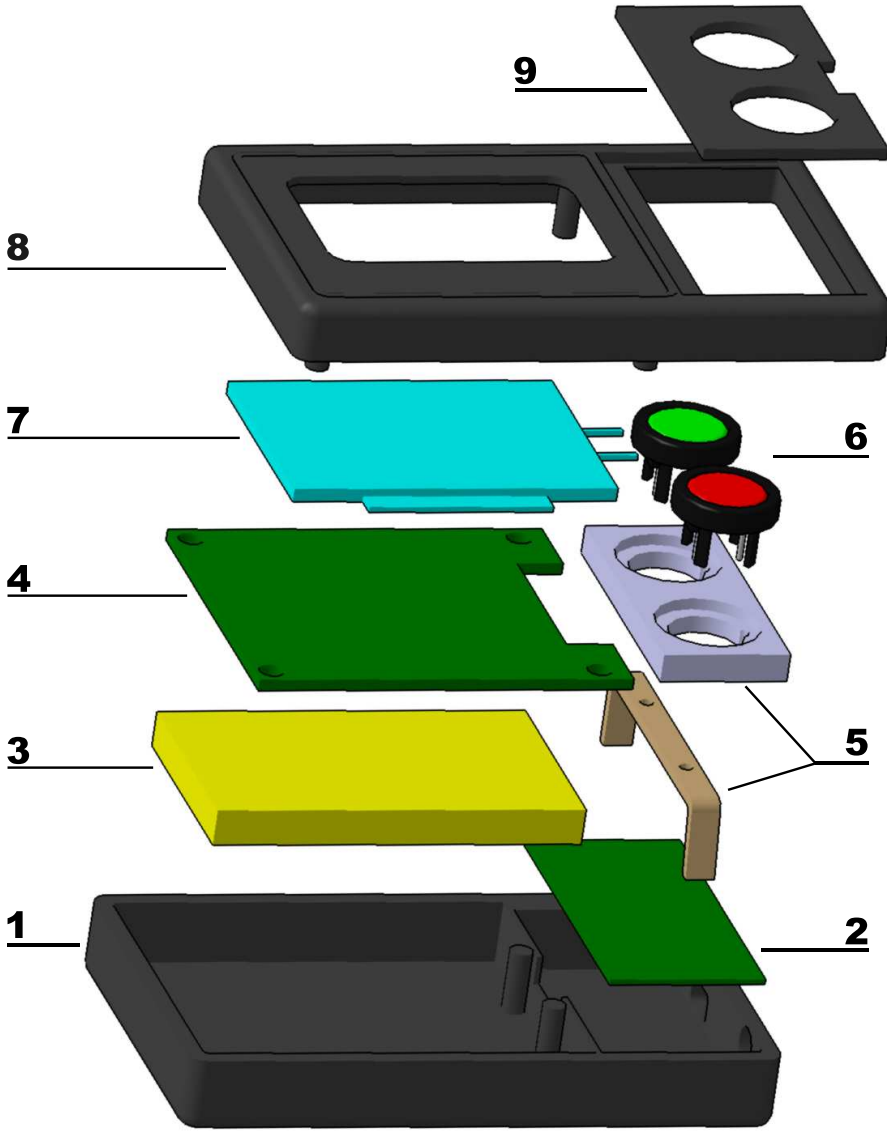
[1] http://sti-ateliers.epfl.ch/page8438.html

and a two layer-design can be easily analyzed for errors. However, a two-layer design is not optimal in a mixed analog/digital configuration. Thus, special precautions must be taken [24]. Moreover, general fabrication rules must be respected (they are given by workshop).

Main constraints associated with the GlucoBox architecture are listed below:

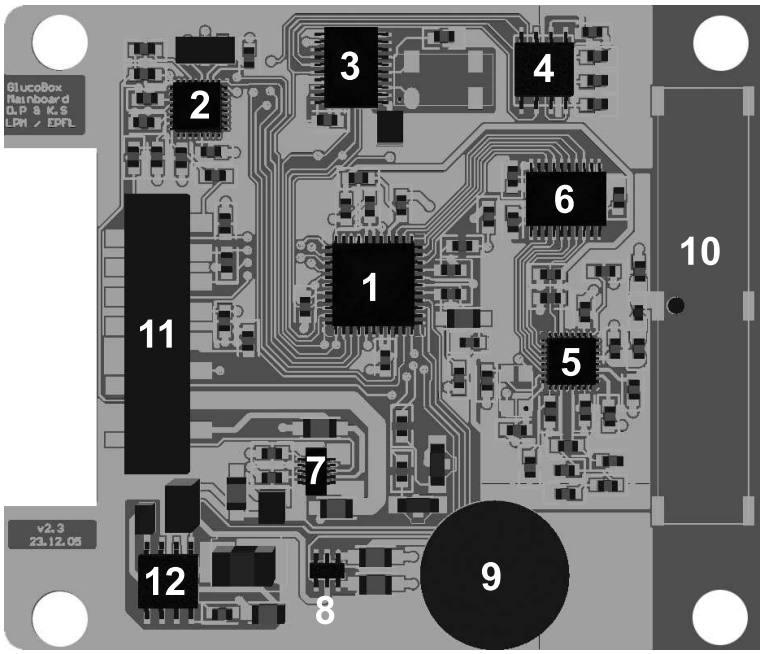
- RF part as far as possible from digital part.
- RF components as close as possible to MICRF506.
- Largest ground plane on the bottom layer (except below the antenna).
- Two separate power planes on top layer.
- No parts or signal below RTC crystal.
- Tracks as short as possible for analog signals.
- LCD connector on the bottom layer.
- Include fixation holes.
- Two PCB – main board and daughter board – connected through a multi-way cable.

It should be noted that all components are all SMD-type, except for buzzer and headers. After taking into account all the rules, the two PCB have been designed, they are shown in the following figures. All schematics can be found in appendix E.



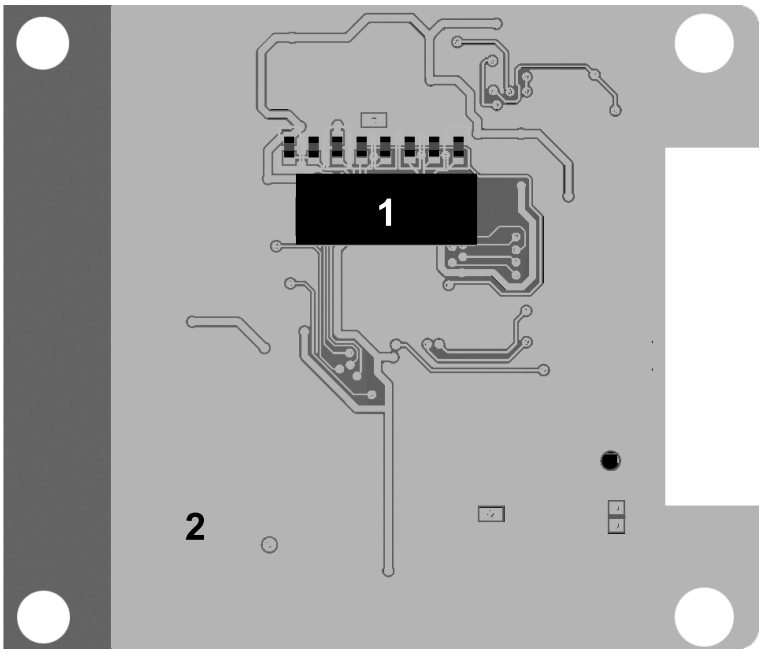
(1) base
(2) daughter PCB
(3) battery
(4) main board PCB
(5) support for push-buttons
(6) push-buttons
(7) LCD display
(8) top cover
(9) top lid

Figure 6.1: mechanical parts used in GlucoBox assembly



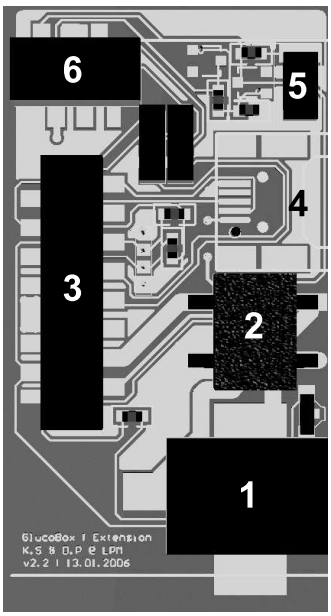
(1) MCU: dsPIC30F4011ML
(2) USB to UART transceiver: FT232BQ
(3) RTC: DS1305E
(4) Non-volatile memory: M45PE80VMP
(5) RF transceiver: MICRF506BML
(6) Level translator: MAX3001E
(7) Power management IC: bq24022DRC
(8) Voltage regulator: MAX8883EUTAQ
(9) Piezoelectric sound transducer
(10) Multilayer ceramic SMD antenna
(11) Connector to daughter board
(12) Voltage inverter: SP4422A

Figure 6.2: top view of the main board



(1) LCD connector (2) Ground plane

Figure 6.3: bottom view of the main board



(1) DC connector
(2) Bridge rectifier
(3) Connector to main board
(4) USB connector
(5) Reset button
(6) Programming connector

Figure 6.4: top view of daughter board

7 TESTS AND RESULTS

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7.2.2 Gathering data and display in PC software 50
7.2.3 Power consumption 51

As we have seen before, the electrical part of our concept is predominant. Therefore, no mechanical "tests" have been made. Electrical test is the first prerequisite for validating our concept. For this purpose, each part of the architecture was tested separately, starting with the power management.

Once all parts had been tested individually, the whole system has been subjected to different tests.

7.1 TEST CONDITIONS

To validate our concept, a bio-sensor is required. Unfortunately, at the test phase of the project, the bio-sensor was not available. In fact, the demonstrator bench module was ready but no measurement was feasible. For this reason, the base module for the bio-sensor has been modified to integrate a temperature sensor (for schematics, refer to appendix E.8 to E.11). Furthermore, the RF part of the module had not yet been validated (as mentioned before, no characterization was made at that time [25]).

In this context, temperature values are fetched in place of glucose levels. The temperature sensor has been programmed so that its response is similar to expected bio-sensor (1 s for making a measurement and value sent is coded on 4 bytes). Moreover, the bio-sensor has been programmed with an defined address and it responses only to a special command.

7.2 RESULTS

Currently, all functional tasks are achieved, according to project requirements. However, one main requirement has not been reached: RF range is less than expected 3 m, as described below.

7.2.1 RF

Based on the reference from MICREL does not always imply good RF performance. Indeed, other factors, such as routing design, proximity of disturbance sources, quality of power supply and antenna, have great influence on RF performance. The PCB design have been made by following basic rules, but no guarantee was to be expected, as stated by a RF specialist[1]. The recommendation was to design the PCB **and then** to evaluate RF performance. This approach is comprehensible as no simulation for such designs can be performed, for lack of electrical models. However, this does not mean that RF performance cannot be improved.

Unfortunately, RF improvements and specific tests (such as power loss and error rate) have not been done due to lack of time and current knowledge. In spite of poor RF performance (maximum range is 20 cm), the concept of the GlucoBox System has been validated, as depicted in the following sections.

7.2.2 Gathering data and display in PC software

Figure 7.1 shows GlucoBox at work, displaying a requested temperature value (alarms set are arbitrary temperatures). For test purposes, the room temperature was sampled by GlucoBox (automatic sampling period of 2 minutes) for a period of 24 hours. At the end of this test, data have been transfered to a PC using the GlucoBox software. A plot of this result is shown in figure 7.2.

Figure 7.1: GlucoBox displaying a reading (1:1 scale)

[1]Mr. Jean-François Zurcher from the LEMA laboratory at EPFL

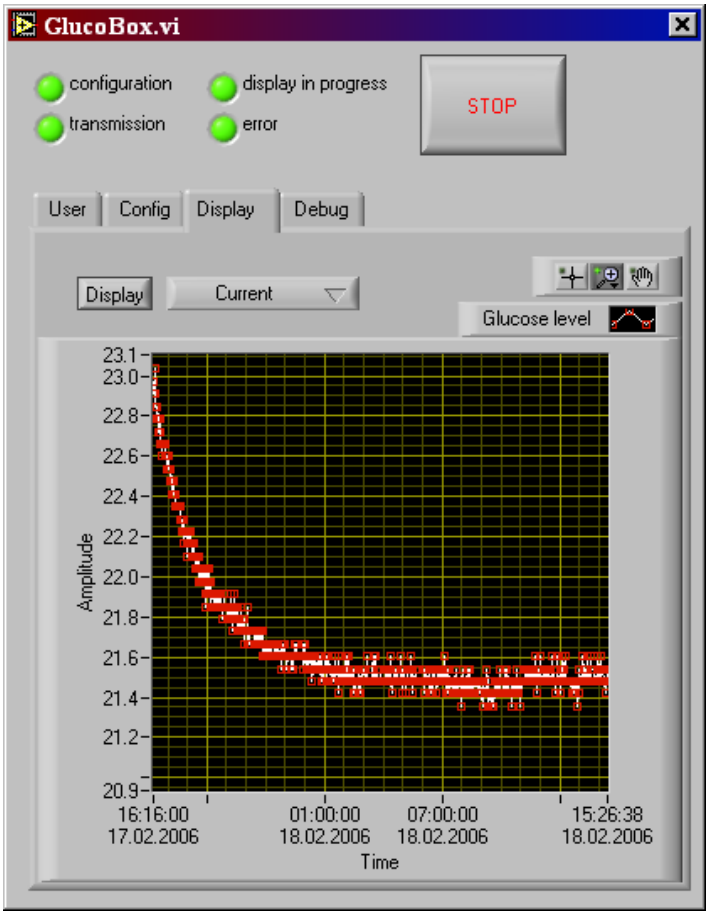

Figure 7.2: temperature plot using GlucoBox software

7.2.3 Power consumption

According to project requirements, at least a week of autonomy is need. Yet, a greater autonomy is achieved by current design, as shown by equations below.

Case of figure (values of current consumption are those measured on actual design):

- automatic measurement each 10 minutes,
- duration of a request: 6 s with no display (worst case),
- duration of display after a manual request: 5 s,
- 2 manual requests in each interval of 10 minutes,
- battery fully charged,
- current level during a request: 70 mA,
- current consuption during display: 40mA,

- current consumption of 5 mA during idle mode,

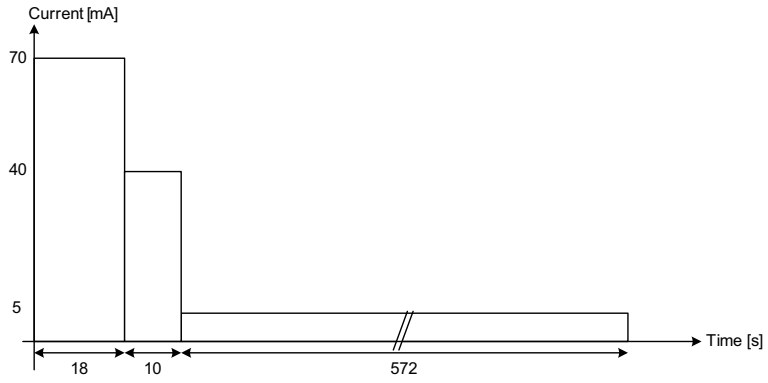

Figure 7.3: power consumption over a period of 10 minutes

The average current consumption is given by:

$$\begin{aligned} \text{mean current} &= \frac{(3 \times 6) \times 70 + (2 \times 5) \times 40 + 572 \times 5}{600} \\ &\approx 8\,\text{mA} \end{aligned}$$

Hence, battery lifetime is given by:

$$\begin{aligned} \text{battery lifetime} &= \frac{1500}{8} \\ &= 187.5\,\text{h} > 7\,\text{days} \end{aligned}$$

8 Conclusion

8.1 Future work

As we have seen in the previous chapter, both hardware and software concepts of the GlucoBox System have been validated. Nevertheless, some important aspects must be reviewed to provide better reliability. These points are (in order of priority):

- RF transmission; sources of malfunction must be identified and corresponding measures must be taken. This part is crucial as without it, the concept is no interest. In case of failure, it is highly recommendable to move to another transceiver. The main reason is that new IC on the market require less critical layout. Moreover, new functionalities are directly implemented in the IC itself, enabling higher communication reliability.
- PC software; some unexpected errors have occurred during utilization and have to be rapidly identified. Moreover, it desirable to have two versions for doctor and patient.
- Debugging of embedded software and optimize code for better performance.
- Integration; the first application GlucoBox System was to operate with a bio-sensor. In this context, it is desirable to test the concept with real bio-sensor as quickly as possible. In this part, the implementation of the RF protocol will also be validated on the bio-sensor.
- Update hardware and software implementation in the MCU, according to manufacturer's up to date information (at this time, not all parameters have been defined !).
- Measure more precisely power consumed by each part and optimize the system's power management.
- Whole system; add and improve functionalities for ease of use.
- Review PCB design for greater performance and to accommodate custom identification used by FTDI IC (an external EEPROM is requires to store vendor information).

8.2 Project conclusion

The initial goal of the project was to develop a simple device to communicate with a bio-sensor, for a demonstrator bench. But, our motivation grew up when we noted that our project can, in a longer term, help people suffering from diabetes. GlucoBox System can be considered as a concept for a future commercial product in the medical field.

This project is very ambitious. Indeed, our role was to build the foundation for the commercial product. In spite of having only few guidelines at the beginning of our project, we

have been able to tackle a typical engineer problem from the beginning to the end. Finally, we ended up with a functional concept in a relatively short period of time.

We hope that our project will be carried on and as a result, lead to the final product. In this scope, some improvements are essential for a key success:

- Mechanical aspect; re-design the enclosure so that is can meet medical regulations. This part will also be profitable to improve external look.
- Electrical; as for mechanical aspect, medical conformity is essential. One of the main part here concerns the wireless link. New IC must be prospected in order to respect medical regulations.
- PC software; portal to common OS, like MAC OSX or Linux.
- Global study: to reduce cost of development, a broader study should be performed. Currently, costs of components of GlucoBox control device are relatively high, around 300 CHF (details in D). New technologies, fabrication processes and assembly techniques must be adequately chosen to achieve lower costs, thus making the system affordable to diabetic patients.

Lausanne, February 24, 2006

Sadasing Kowlessur Damien Perritaz

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During the realization of this project, we were kindly guided and helped by many persons. We would like to thank these persons for their support and advice:

- Mr. Eric Meurville and Mr. Léandre Bolomey (both from the LPM laboratory), our assistants for this project.
- Mr. Jean-François Zurcher (LEMA/EPFL) who kindly gave us practical advice on RF designs.
- Mr. Corradini Giancarlo (LPM/EPFL) who helped us to mount our PCB components.
- Mrs. Irma Blanco (CHUV) for her precious information on glucometers and patients' needs.
- Mr. Michel Tille (Electronitel SA) was our contact for MICREL parts.
- Mr. Julien Chassot (LPM/EPFL) for his encouragement us throughout the project.
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A Device Specifications

General

Dimensions (WxHxD)	62 x 23 x 103 mm
Weight	115 g
Case	black ABS plastic
Display type	LCD 128 x 64 pixels with backlight

Electrical

Built-in rechargeable battery capacity	1500 mAh at 3.7 V
Charger voltage	max. 6 Volts
Charger current	min. 800 mA
Charger polarity	positive or negative centered DC - jack
USB current consumption (charge mode)	max. 100 mA
Charge time from AC adapter	max. 3 hours
Charge time from USB (max. 100 mA)	max. 18 hours

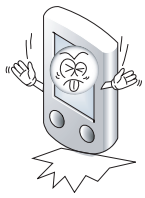
PC requirements

Pentium 200 MHz or greater
256 Mb or RAM
Windows XP
VGA 800x600 or above
100 Mb of available hard disk space
CD-ROM drive (2x speed or greater)
USB 2.0 port (1.1 not supported)

B GlucoBox User Manual

B.1 Safety Instructions

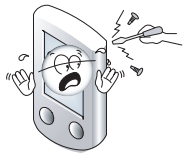
Do not expose to extreme temperatures (above 85 °C or below 5 °C). Do not expose to moisture.



Do not apply excessive pressure on the device.

Do not let any foreign matter spill into the device.

Do not expose to chemicals such as benzene and thinners.

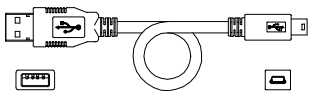


Do not try to disassemble and repair the device yourself.

Do not touch the charger with wet hands.

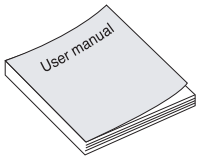
B.2 Components

GlucoBox Control Device

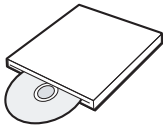


USB cable (male A ↔ male mini-B)

AC Adapter

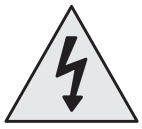


User Manual



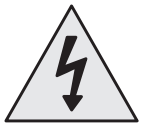
Installation CD

B.3 BATTERY CHARGER SAFETY



CAUTION

RISK OF ELECTRIC SHOCK. DO NOT OPEN



The uninsulated parts inside the charger could cause electric shock.
For your safety, do not open the case of the charger.

Read this User Manual to prevent any problems that may occur while using the charger.

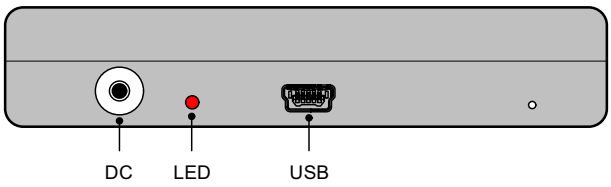
Warning

- Use the charger away from water sources to avoid fire or electric shock.

Caution

- To avoid electric shock, use the charger only with a 220V power outlet.
- Make sure that the charger's plug is inserted all the way into the outlet.

B.4 Charging The Battery



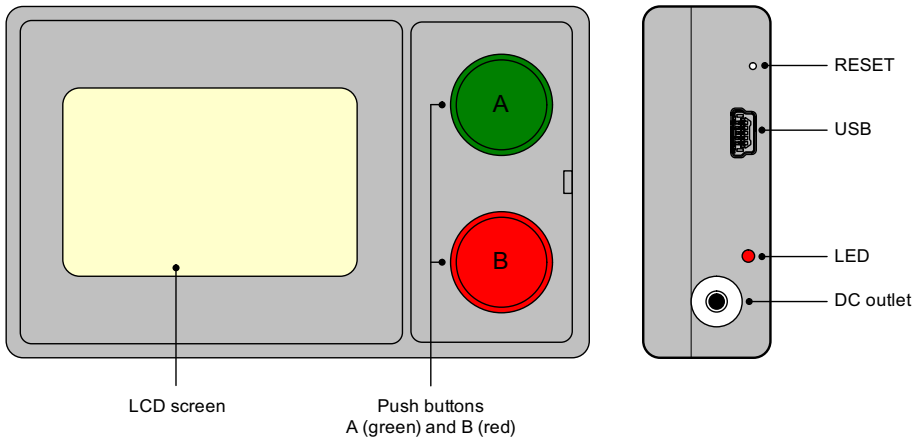
▷ With AC adapter

- Plug the charger into a wall outlet.
- Connect DC-jack of charger to DC outlet on device LED will lights up.
- When charge is complete, battery logo will be full.

▷ With USB port

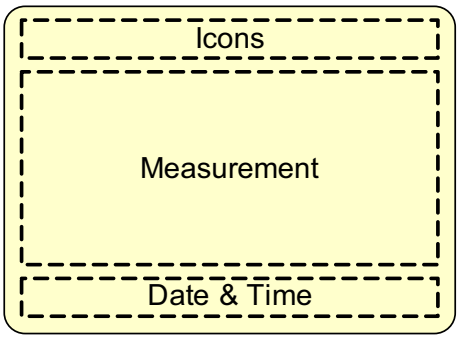
- Plug the USB cable into the USB port of your PC.
- Connect mini-USB end of cable to the device and LED lights up.
- Charging starts automatically and continues even when using software.

B.5 Location Of Controls



Note: if reset of the device is required, press the RESET hole using a pointed object such as a safety clip.

B.6 Display



The display is divided into three zones:

▷ Measurement

In this zone, glucose level values are displayed. Units mmol/l are **not** displayed.

▷ Date & Time

Date and time are displayed in this area.

▷ Icons

Status of the device is displayed in this zone. The icons and their corresponding signification are listed below.

Icon	Description
	battery level indicator
	alarm indicator
	memory full
	general failure
	indicates whether sound is activated or not
	RF communication is in progress
	communication between device and PC has been established
	automatic measurement acquisition

Table B.1: icons displayed on top part of LCD screen

B.7 Connection GlucoBox Control Device To Your PC

The drivers must be installed prior to using GlucoBox software.

B.7.1 System Requirements

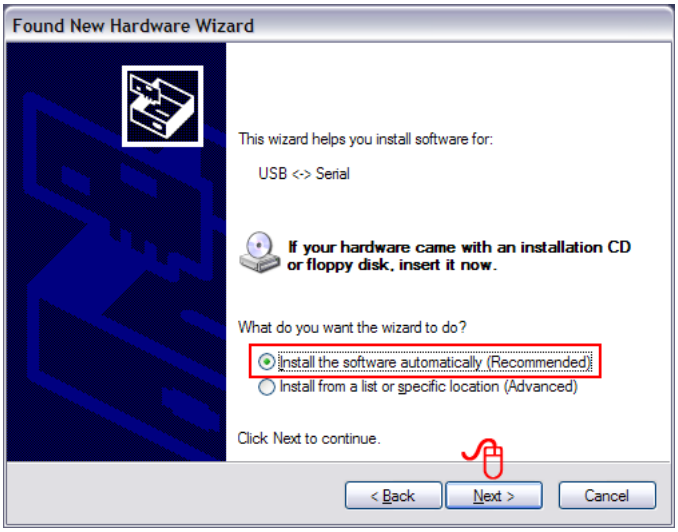
- Pentium 200 MHz or greater
- 256 Mb or RAM
- Windows XP
- VGA 800x600 or above
- 100 Mb of available hard disk space
- CD-ROM drive (2x speed or greater)
- USB 2.0 port (1.1 not supported)

B.7.2 Installing Drivers

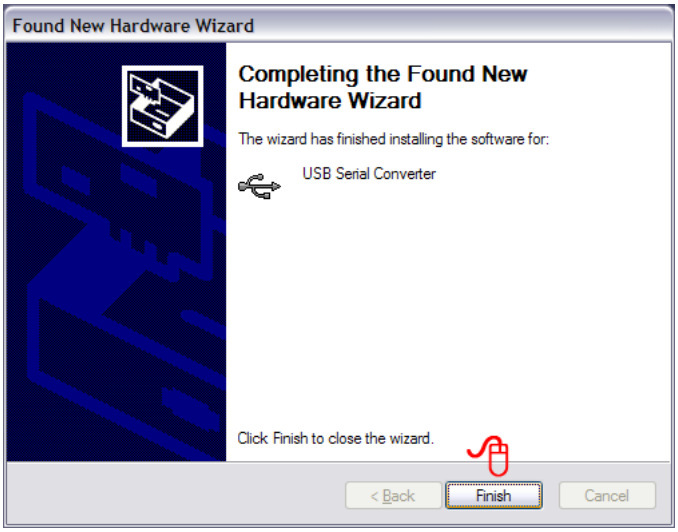
▷ Insert the installation CD into your CD-ROM drive.
▷ Plug the USB cable into your PC and to GlucoBox control device. Windows XP should automatically detect a new hardware and will start installation process.

Found New Hardware Wizard
Welcome to the Found New Hardware Wizard
Windows will search for current and updated software by looking on your computer, on the hardware installation CD, or on the Windows Update Web site (with your permission).
Read our privacy policy
Can Windows connect to Windows Update to search for software?
Yes, this time only
Yes, now and every time I connect a device
No, not this time
Click Next to continue.
< Back
Next >
Cancel

▷ Choose “No, not this time” and click on“Next”.


Found New Hardware Wizard
This wizard helps you install software for:
USB <-> Serial
If your hardware came with an installation CD or floppy disk, insert it now.
What do you want the wizard to do?
Install the software automatically (Recommended)
Install from a list or specific location (Advanced)
Click Next to continue.
< Back
Next >
Cancel

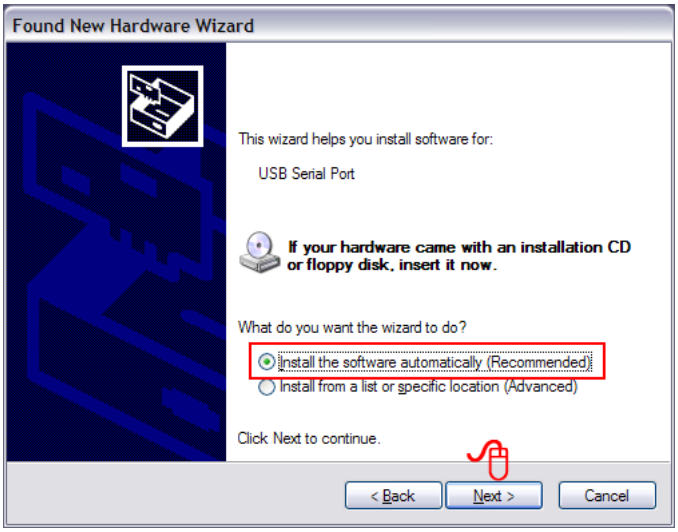
▷ Choose “Install the software automatically” and click on “Next”.



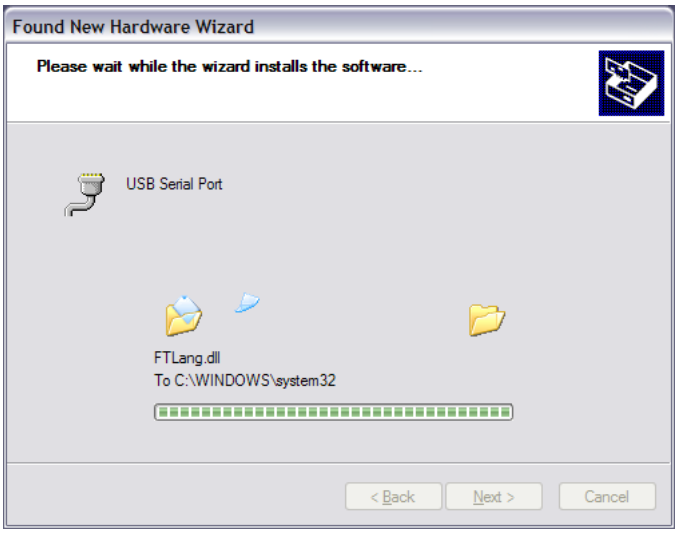
▷ Click on “Finish” to continue.

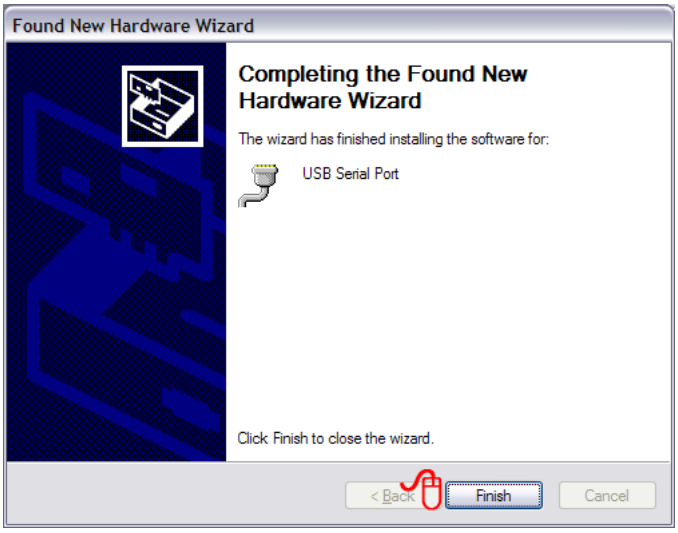
Found New Hardware Wizard
Welcome to the Found New Hardware Wizard
Windows will search for current and updated software by looking on your computer, on the hardware installation CD, or on the Windows Update Web site (with your permission).
Read our privacy policy
Can Windows connect to Windows Update to search for software?
Yes, this time only
Yes, now and every time I connect a device
No, not this time
Click Next to continue.
< Back
Next >
Cancel

▷ Choose “No, not this time” and click on “Next”.


Found New Hardware Wizard
This wizard helps you install software for:
USB Serial Port
If your hardware came with an installation CD or floppy disk, insert it now.
What do you want the wizard to do?
Install the software automatically (Recommended)
Install from a list or specific location (Advanced)
Click Next to continue.
< Back
Next >
Cancel

▷ Choose “Install the software automatically” and click on “Next”.





▷ Click “Finish” to end installation. You should a confirmation in your task bar.

B.7.3 VERIFY CORRECT INSTALLATION OF DRIVERS

▷ Launch WindowsXP device manager: Windows Key + Pause or right-click on My Computer and choose Properties.

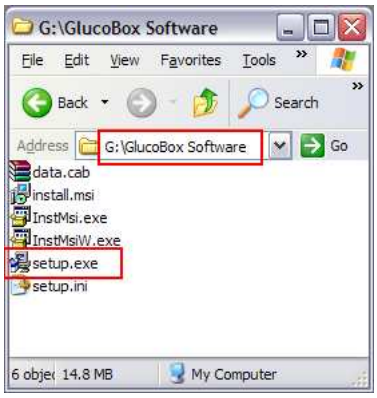
System Properties
System Restore
Automatic Updates
Remote
General
Computer Name
Hardware
Advanced
Device Manager
The Device Manager lists all the hardware devices installed on your computer. Use the Device Manager to change the properties of any device.
Device Manager
Drivers
Driver Signing lets you make sure that installed drivers are compatible with Windows. Windows Update lets you set up how Windows connects to Windows Update for drivers.
Driver Signing
Windows Update
Hardware Profiles
Hardware profiles provide a way for you to set up and store different hardware configurations.
Hardware Profiles
OK
Cancel
Apply

▷ Choose "Hardware" tab and click on "Device Manager".

▷ Under "Ports (COM & LPT)" there must be "USB Serial Port (COMx)", where x denotes the communication port to be used in GlucoBox Software.

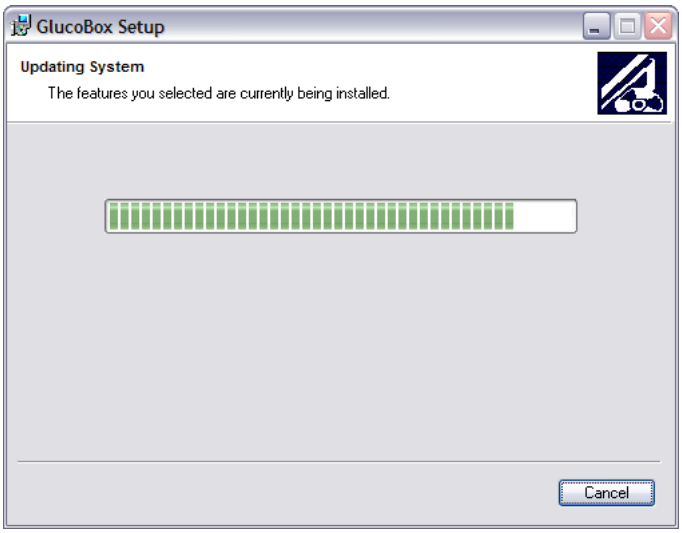
B.7.4 Installing GlucoBox Software

▷ Insert the installation CD in your CD-ROM drive. Execute "setup.exe" found in "GlucoBox Software" directory.

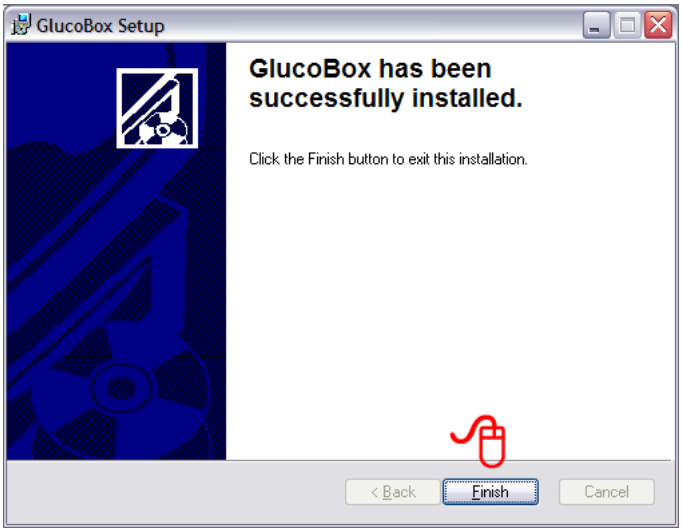


▷ Click on "Next" to start installation and follow instructions.

GlucoBox Setup
Welcome to the GlucoBox Installation Wizard
It is strongly recommended that you exit all Windows programs before running this setup program.
Click Cancel to quit the setup program, then close any programs you have running. Click Next to continue the installation.
WARNING: This program is protected by copyright law and international treaties.
Unauthorized reproduction or distribution of this program, or any portion of it, may result in severe civil and criminal penalties, and will be prosecuted to the maximum extent possible under law.
< Back
Next >
Cancel



▷ Click on “Finish” to end installation process.

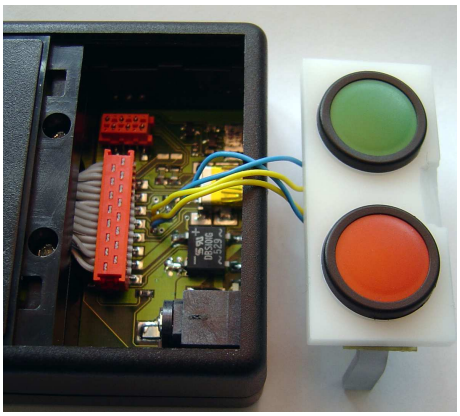


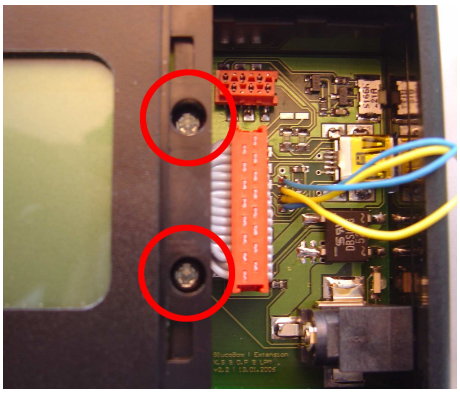
C Technical User Manual

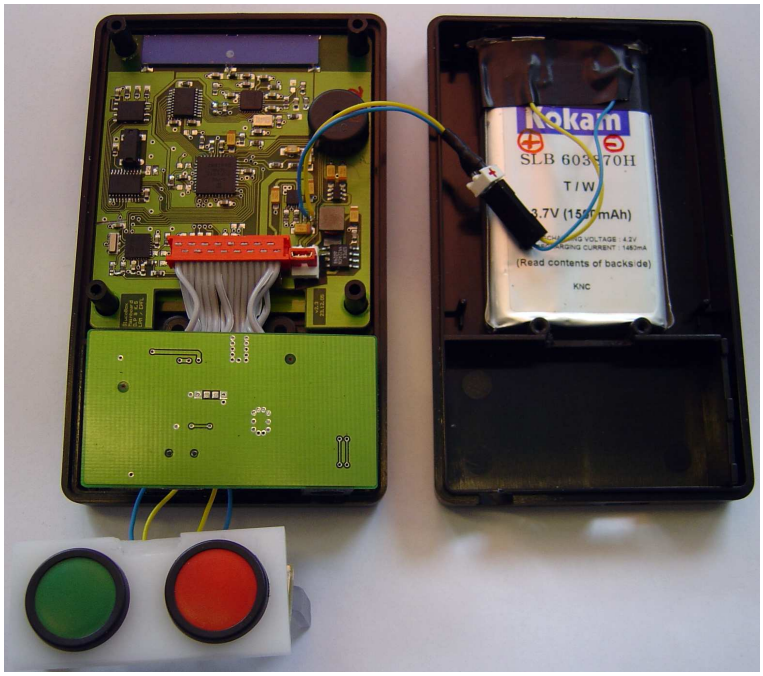
C.1 Software Used

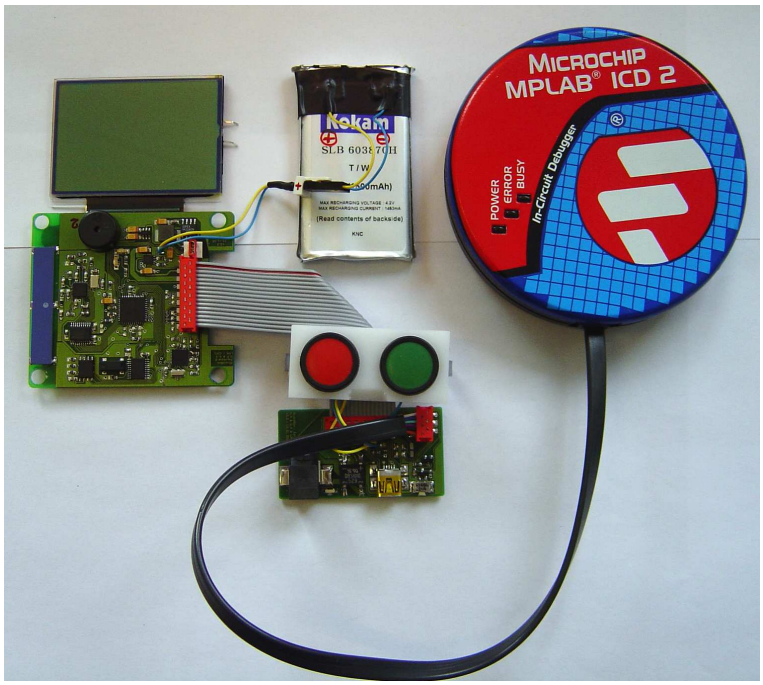
- MPLAB, v 7.22
- C30 C compiler for dsPIC, v 1.33
- LabView for Windows, v 7.0
- Matlab, v 7.1
- Catia, v P3 VR 11
- DXP 2004, build 8.0.4.1272

C.2 Accessing programming interface






Kokam
SLB 603870H
T/W
(Read contents of backside)
KNC


Kokam
SLB 603870H
T/W
(Read contents of backside)
KNC
MICROCHIP
MPLAB® ICD 2
POWER
ERROR
BUSY
In-Circuit Debugger

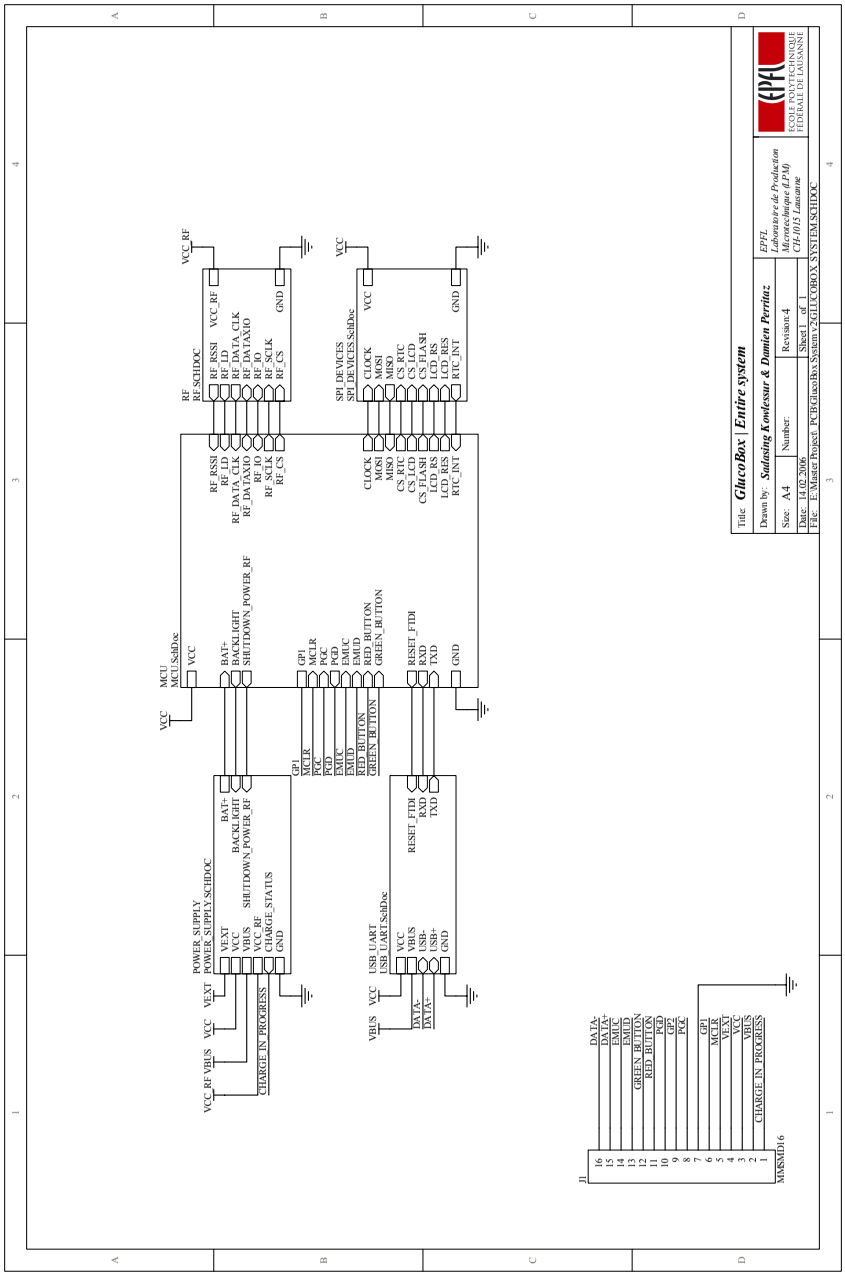
D Cost calculation

COMPONENTS	COST (CHF)
TOTAL	**315**
display	**83**
LCD module	79
backlight IC	4
power supply	**61**
battery	48
charger IC	6
voltage regulator	3
level translator	3
bridge rectifier	1
RF	**56**
antenna	36
RF IC	15
crystal 16 MHz	5
mechanical	**44**
buttons	30
enclosure	14
MCU	**23**
time management	**14**
super-capacitor	5
crystal 32.768 kHz	5
RTC IC	4
USB transceiver	**7**
FTDI IC	5
resonator 6 MHz	2
flash memory	**3**
buzzer alarm	**2**
miscellaneous	**22**
connector	14
resistor, capacitor, ...	8

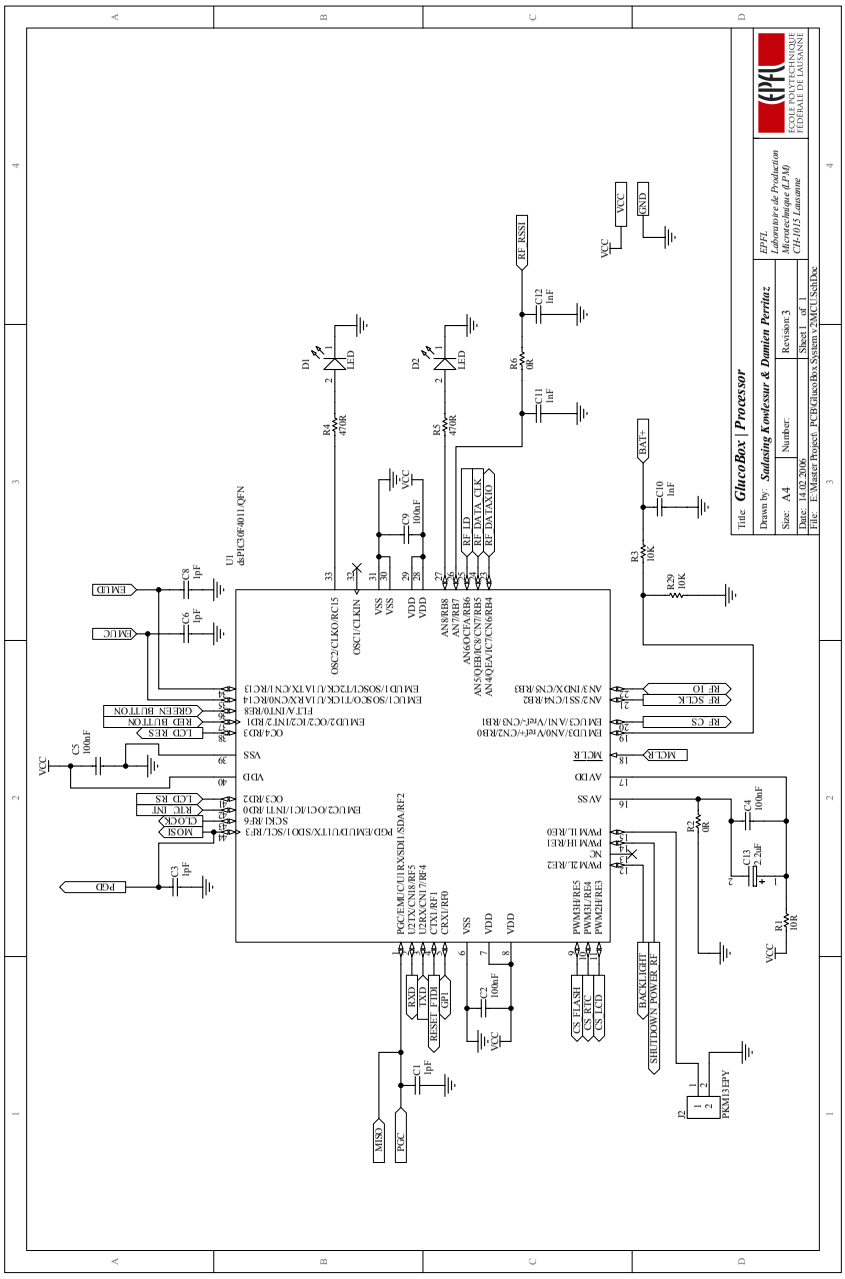
Table D.1: cost of the GlucoBox components

E ELECTRICAL SCHEMATICS

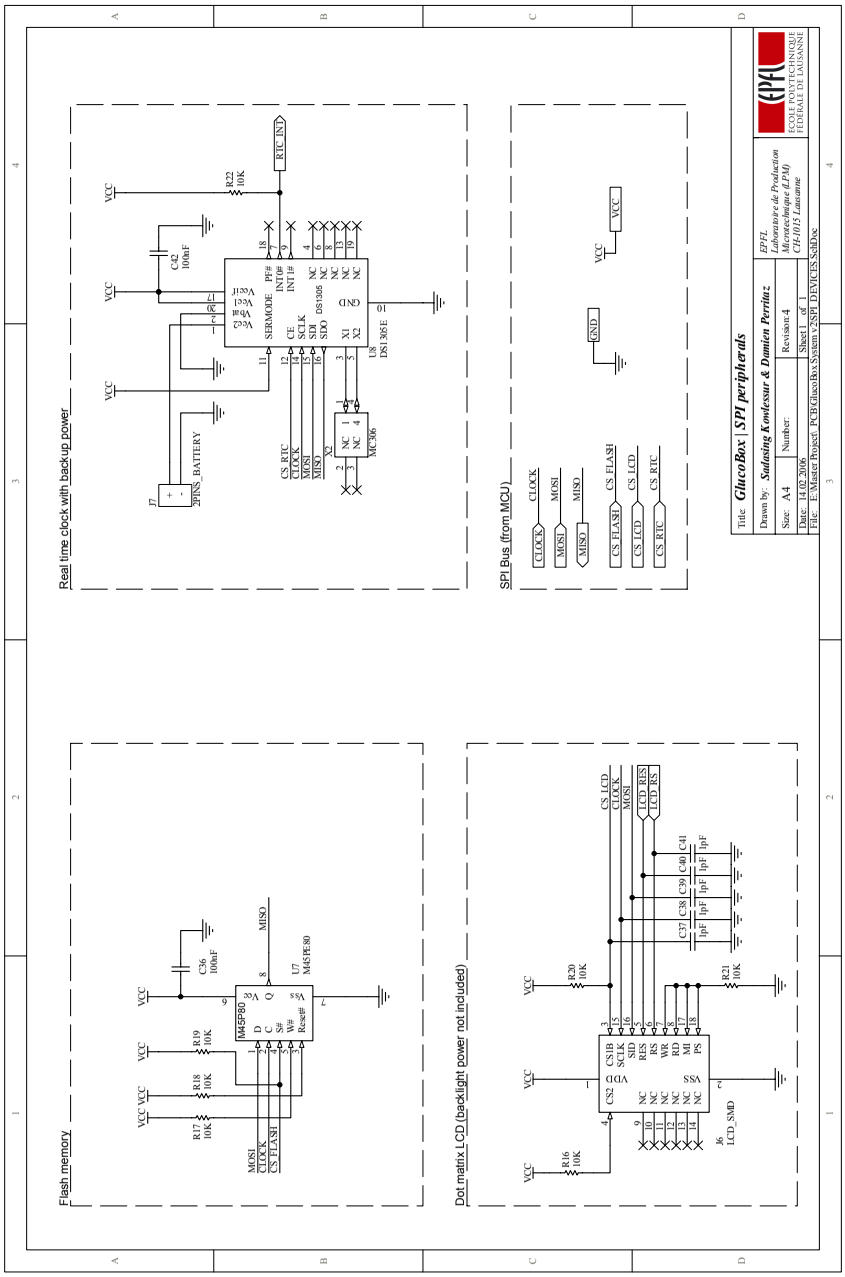
E.1 MAINBOARD



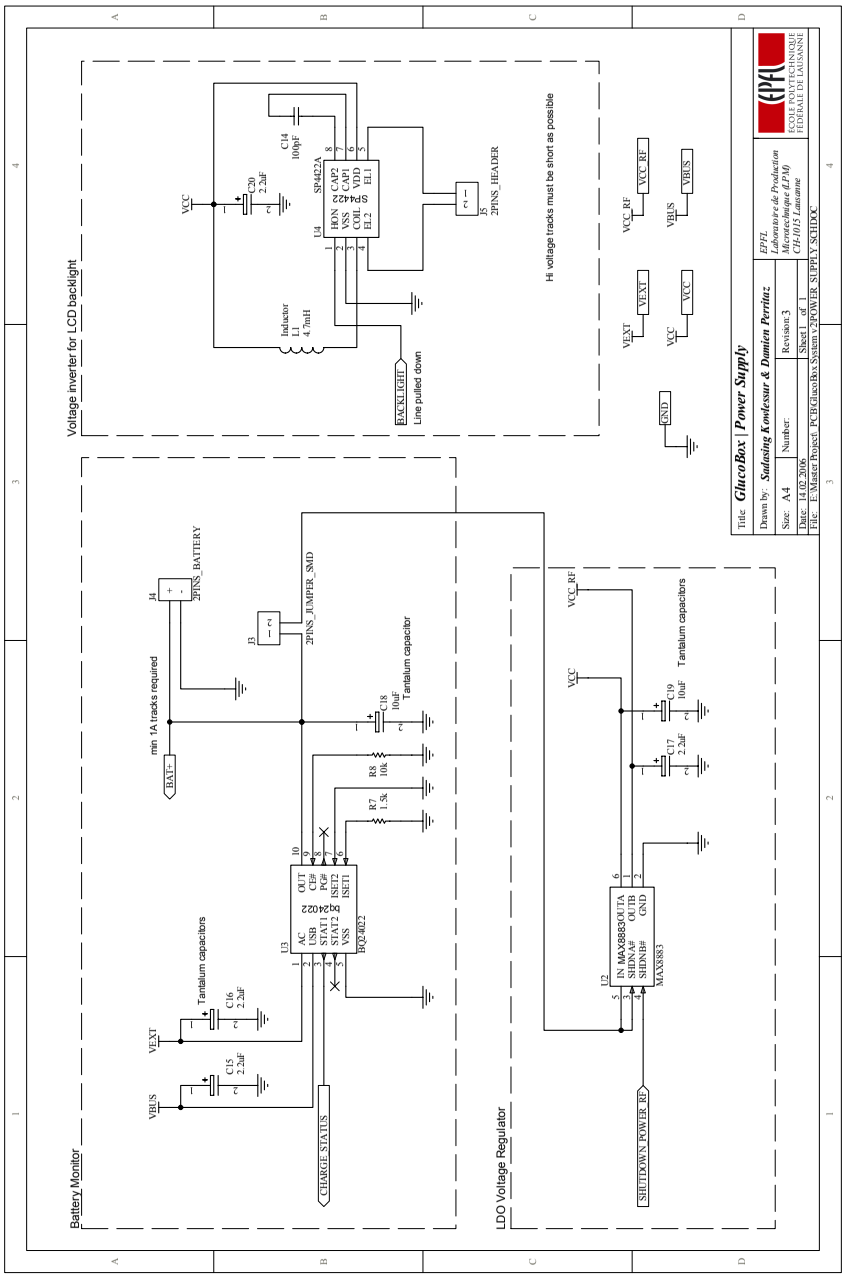
E.2 MCU


Title: GlucoBox | Processor
Drawn by: Sadasing Kowlessur & Damien Perritaz
Size: A4
Number:
Revision: 3
Sheet 1 of 1
Date: 14/02/2006
File: E:\Master Project\PCB\GlucoBox System 2\SCH\ GlcSubDoc
EPFL Laboratoire de Production Microhydraulique (LPM) CH-1015 Lausanne
ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
U1
dsPIC30F4011-QFN
OSC2/CLKO/RC15
OSC1/CLKIN
VSS
VDD
AN8/RB8
AN7/RB7
AN6/OCFA/RB6
AN5/QEB/IC7/RB5
AN4/QEA/IC7/CN6/RB4
EMUD1/SOSCI/T2CK/U1TX/CN1/RC13
EMUC1/SOSCO/T1CK/U1RX/CN0/RC14
EMUD2/OC2/IC2/INT2/RD1
OC1/RD0
EMUC2/OC1/IC1/INT1/RD0
SCK1/RF6
SDI1/RF7
SDO1/SDA/RF8
U2TX/CN18/RF5
U2RX/CN17/RF4
C1TX/RF1
C1RX/RF0
PGD/EMUD/U1TX/SDO1/SCL/RF3
PGC/EMUC/U1RX/SDI1/SDA/RF2
AN2/SS1/CN4/RB2
AN3/INDX/CN5/RB3
EMUD3/AN0/VREF+/CN2/RB0
EMUC3/AN1/VREF-/CN3/RB1
PWM1L/RE0
PWM1H/RE1
PWM2L/RE2
NC
PWM2H/RE5
PWM3L/RE4
PWM3H/RE3
MCLR
AVDD
AVSS
VCC
GND
BAT+
RF_RSSI
RF_DATA_CLK
RF_DATAIO
RF_DATA
RF_CS
RF_SCLK
RF_IO
LCD_RES
READ_BUTTON
GREEN_BUTTON
LCD_RS
LCD_INT
CLOCK
MOSI
MISO
SCK
RXD
TXD
RESET_FTDI
GPI
CS_FLASH
CS_RTC
CS_LCD
BACKLIGHT
SHUTDOWN_POWER_RF
PGD
PGC
D1
D2
LED
R1 10K
R2 0R
R3 10K
R4 470R
R5 470R
R6 0R
R29 10K
C1 1pF
C2 100nF
C3 1pF
C4 100nF
C5 100nF
C6 1pF
C8 1pF
C9 100nF
C10 1nF
C11 1nF
C12 1nF
C13 2.2nF
J2
PKM13EPY

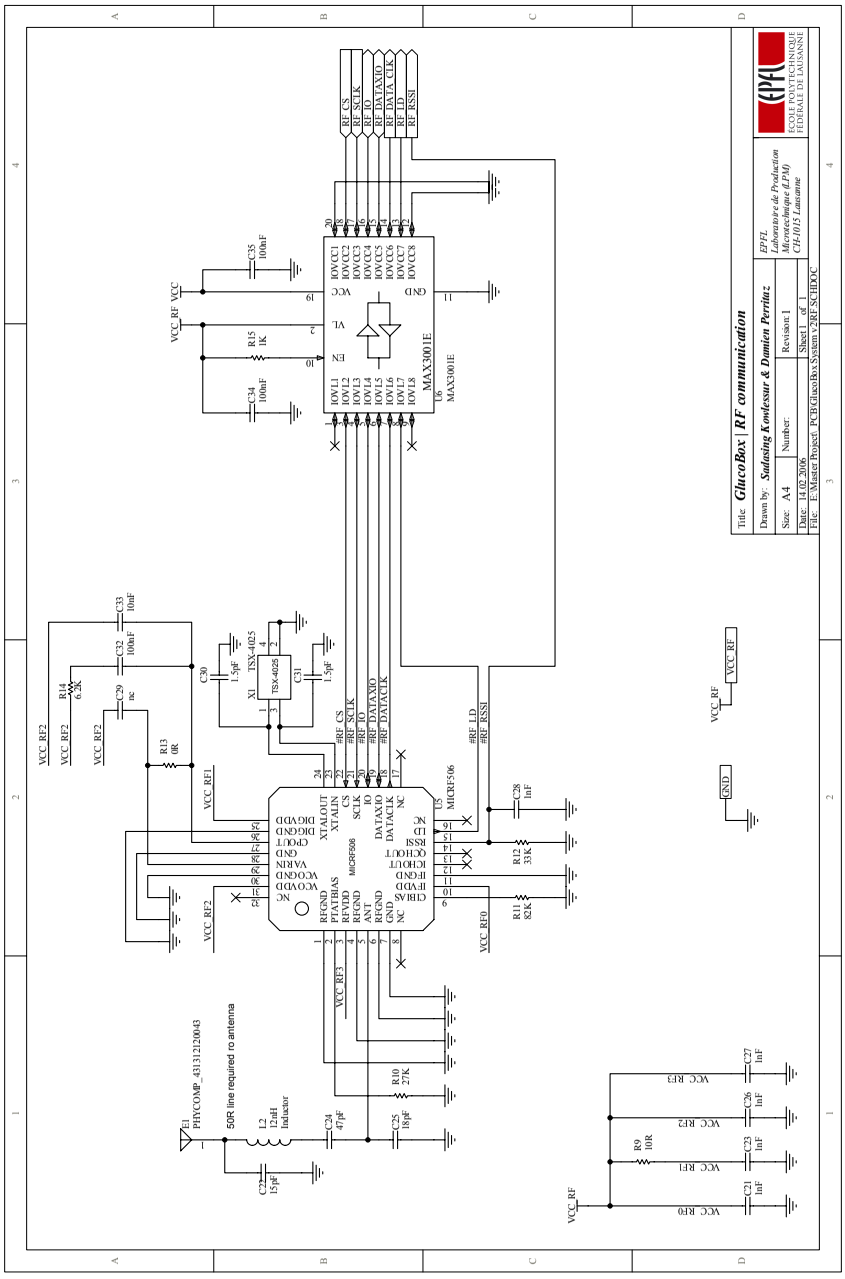
E.3 PERIPHERALS



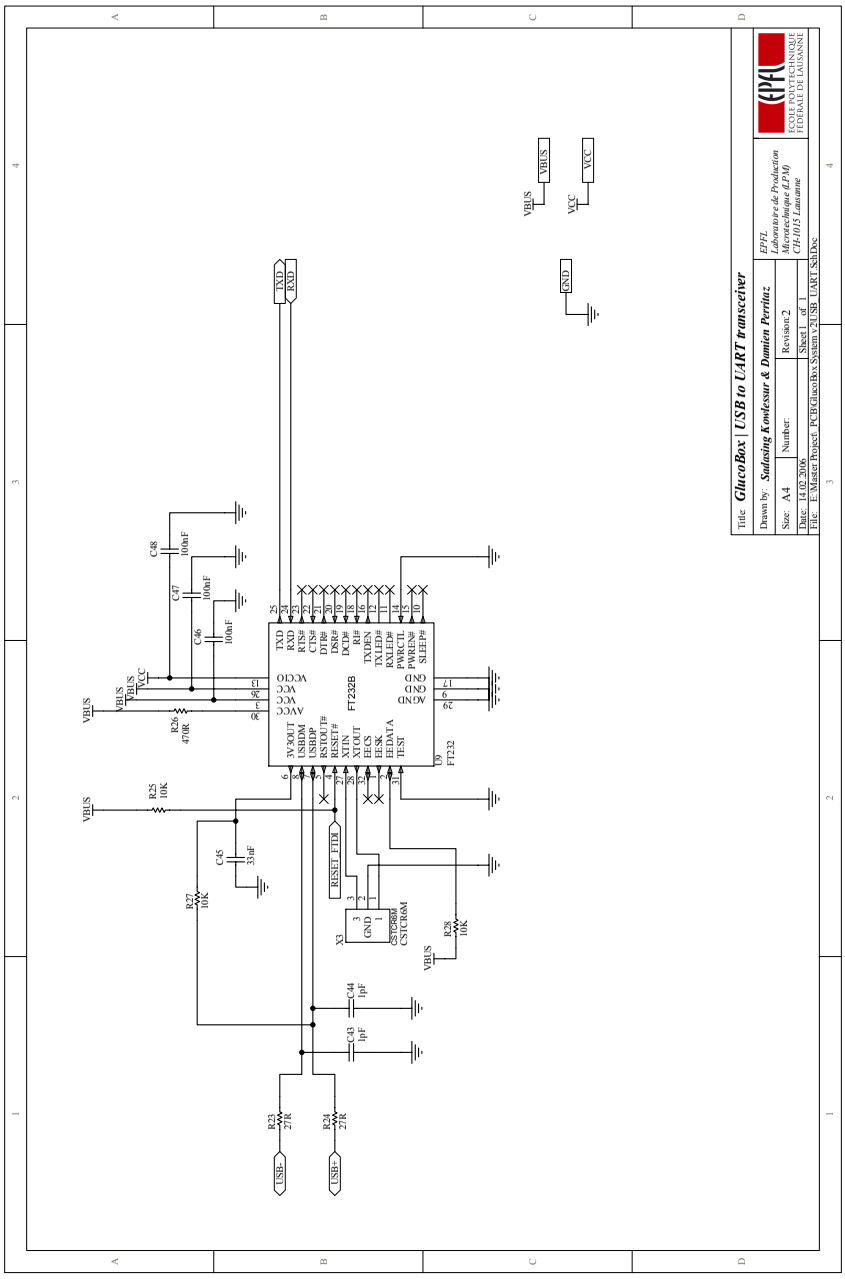
E.4 POWER SUPPLY



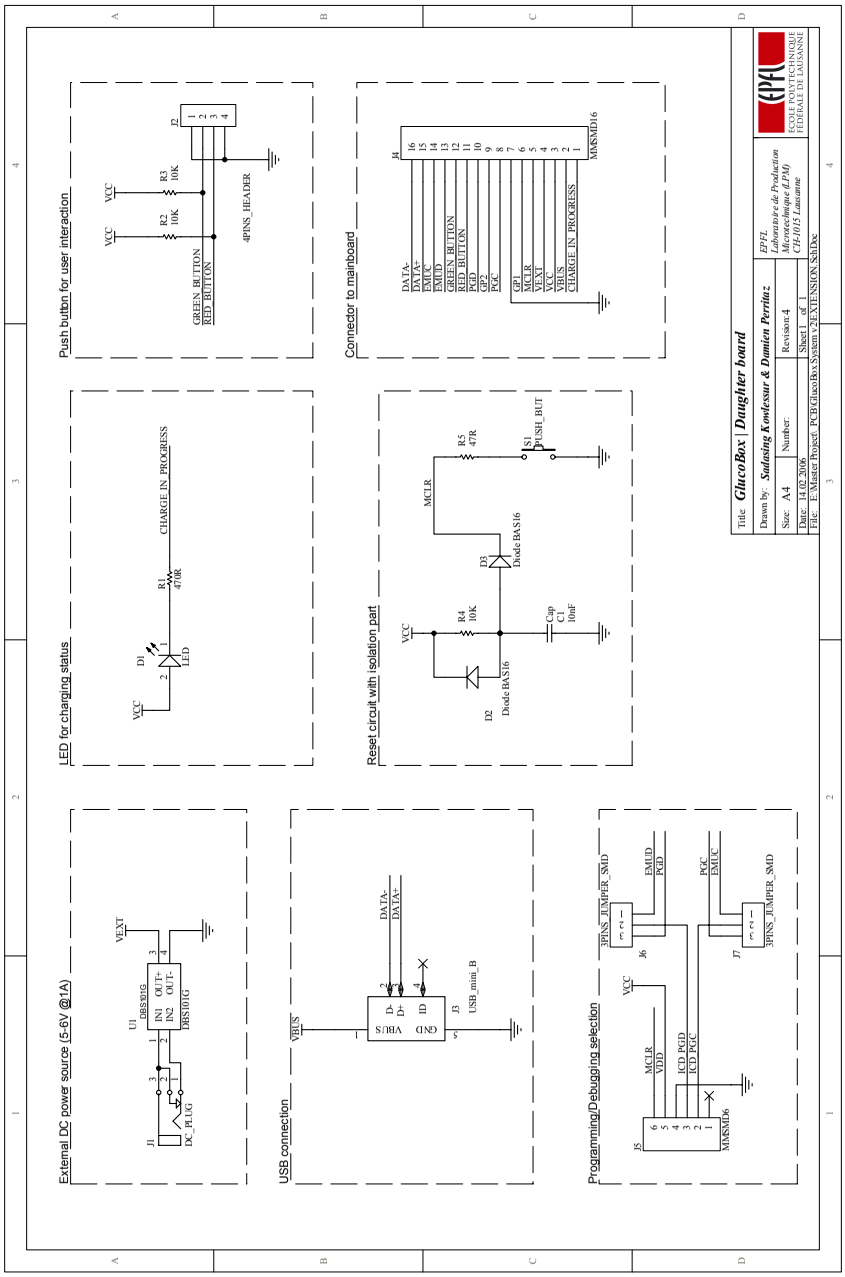
E.5 RF


Title: GlucoBox | RF communication
Drawn by: Sadasing Kowlessur & Damien Perritaz
Size: A4
Number:
Revision: 1
Date: 13/02/2006
Sheet 1 of 1
File: E:\Master Project\ PCB\GlucoBox System 1\2M-SCHDOC
EPFL
Laboratoire de Production Microtechnique (LPM)
CH-1015 Lausanne
ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
MAX3001E
MICRF506
TSX-4025
PHYCOMP_4313123120043
50R line required ro antenna
RF_CS
RF_SCLK
RF_IO
RF_DATAXIO
RF_DATA_CLK
RF_LD
RF_RSSI
VCC_RF
GND

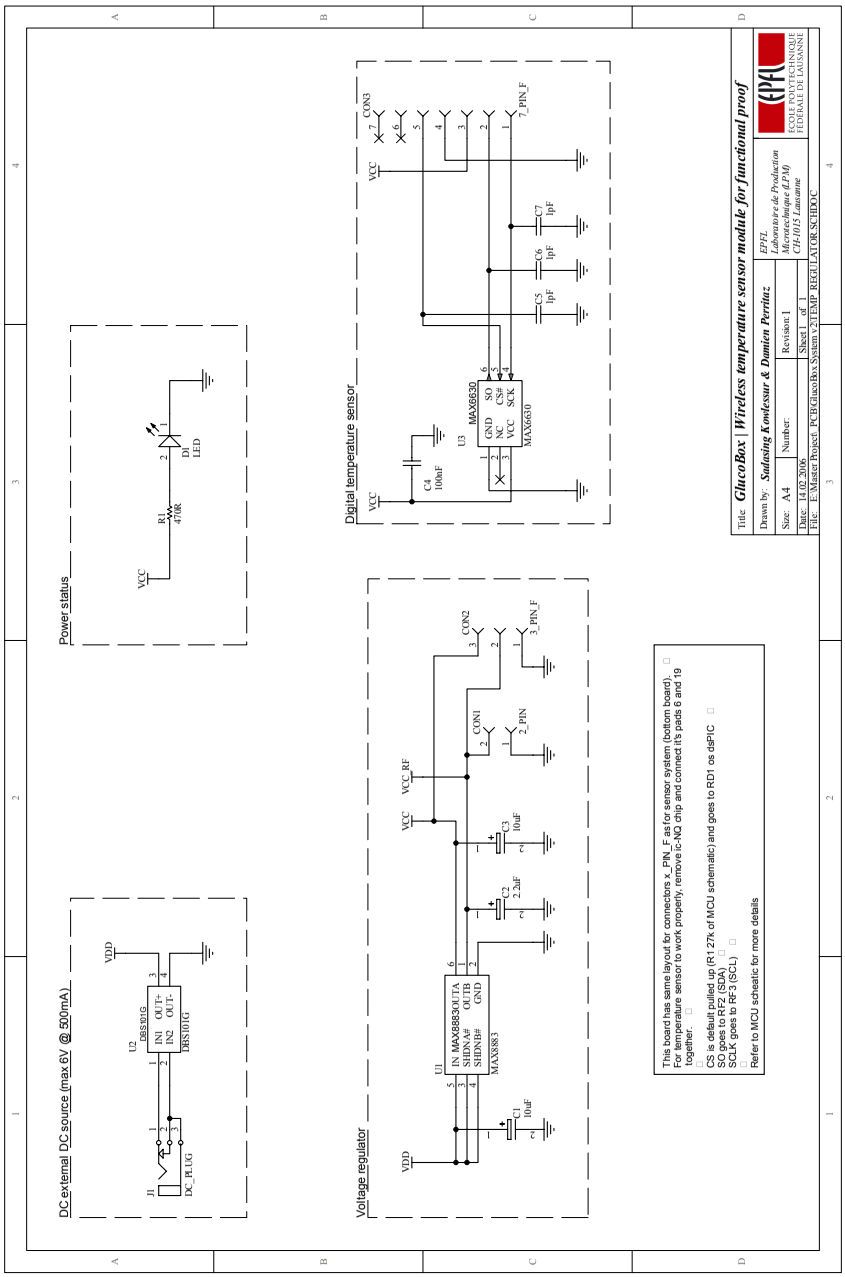
E.6 USB


Title: GlucoBox | USB to UART transceiver
Drawn by: Sodasing Kowlessur & Damien Perritaz
Size: A4
Number:
Revision: 2
Date: 14.02.2006
Sheet 1 of 1
File: E:\Master Project\PCB\GlucoBox System V2\USB_UART_SchDoc
EPFL
Laboratoire de Production Microtechnique (LPM)
CH-1015 Lausanne
ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
VBUS
VCC
GND
TXD
RXD
USB-
USB+
RESET_FTDI
FT232B
FT232
C48 100nF
C47 100nF
C46 100nF
C45 33nF
C44 1pF
C43 1pF
R23 27R
R24 27R
R25 10K
R26 470R
R27 10K
R28 10K
X3 GND 3 1 2 CSTCR6M00G15AB-R0 CSTCR6M0

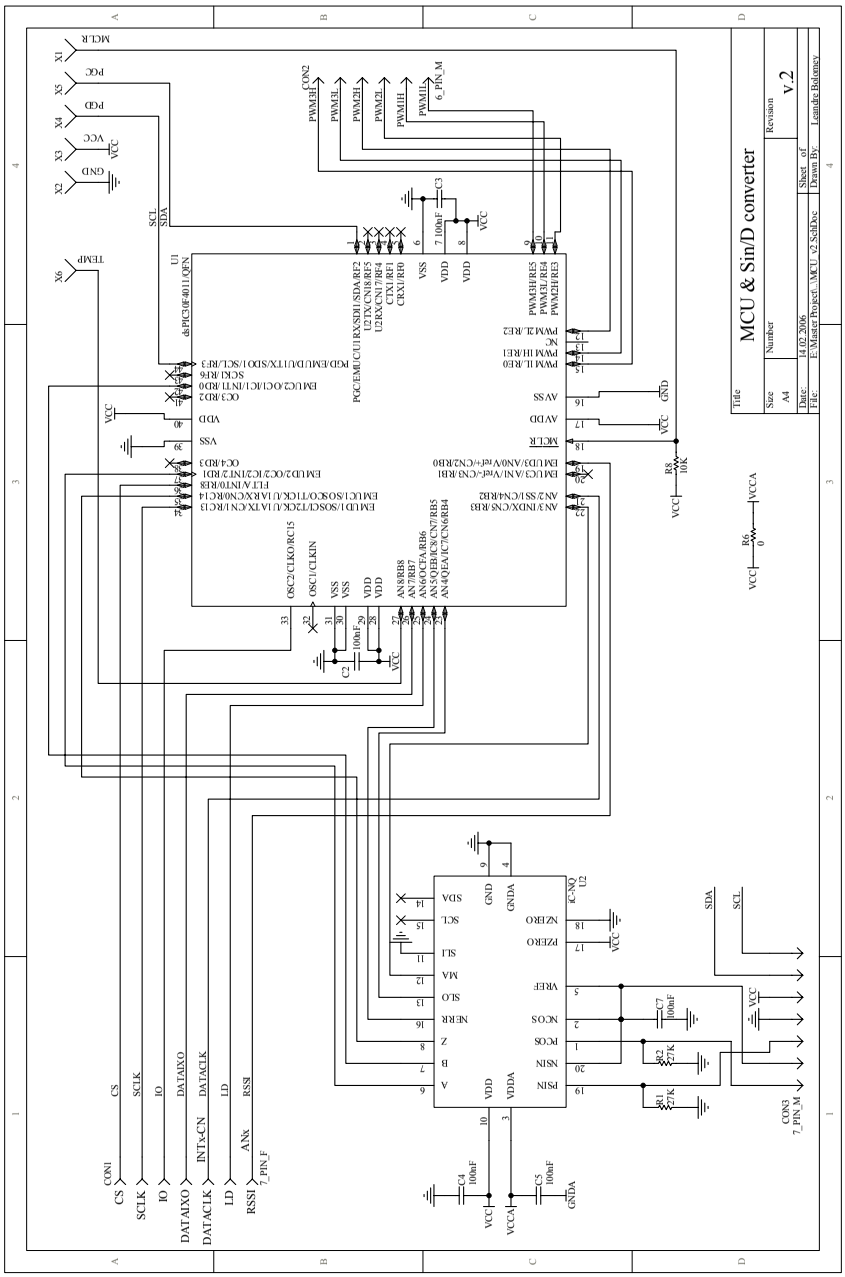
E.7 DAUGHTER BOARD



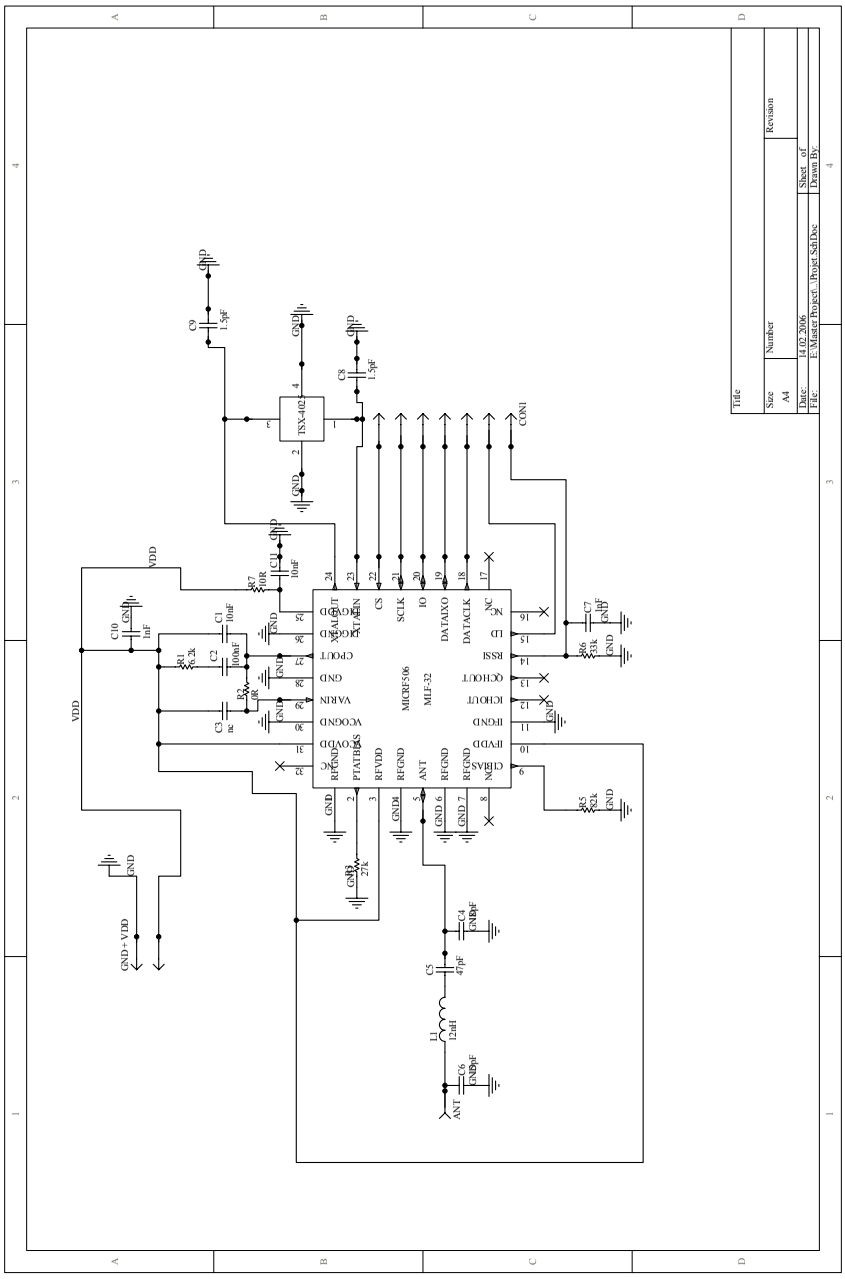
E.8 TEMPERATURE SENSOR BASE


DC external DC source (max 6V @ 500mA)
Power status
Digital temperature sensor
Voltage regulator
Title: GlucoBox | Wireless temperature sensor module for functional proof
Drawn by: Sadasing Kowlessur & Damien Perritaz
Size: A4
Number:
Revision: 1
Sheet 1 of 1
Date: 14.02.2006
File: E:\Master Project\PCB\GlucoBox System V2\TEMP_REG\LATOR_SCHEDC
EPFL
Laboratoire de Production Microtechnique (LPM)
CH-1015 Lausanne
ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
This board has same layout for connectors x_PIN_F as for sensor system (bottom board).
For temperature sensor to work properly, remove IC-NQ chip and connect it's pads 6 and 19 together.
CS is default pulled up (R1 27k of MCU schematic) and goes to RD1 os dsPIC
SO goes to RF2 (SDA)
SCLK goes to RF3 (SCL)
Refer to MCU schealtic for more details

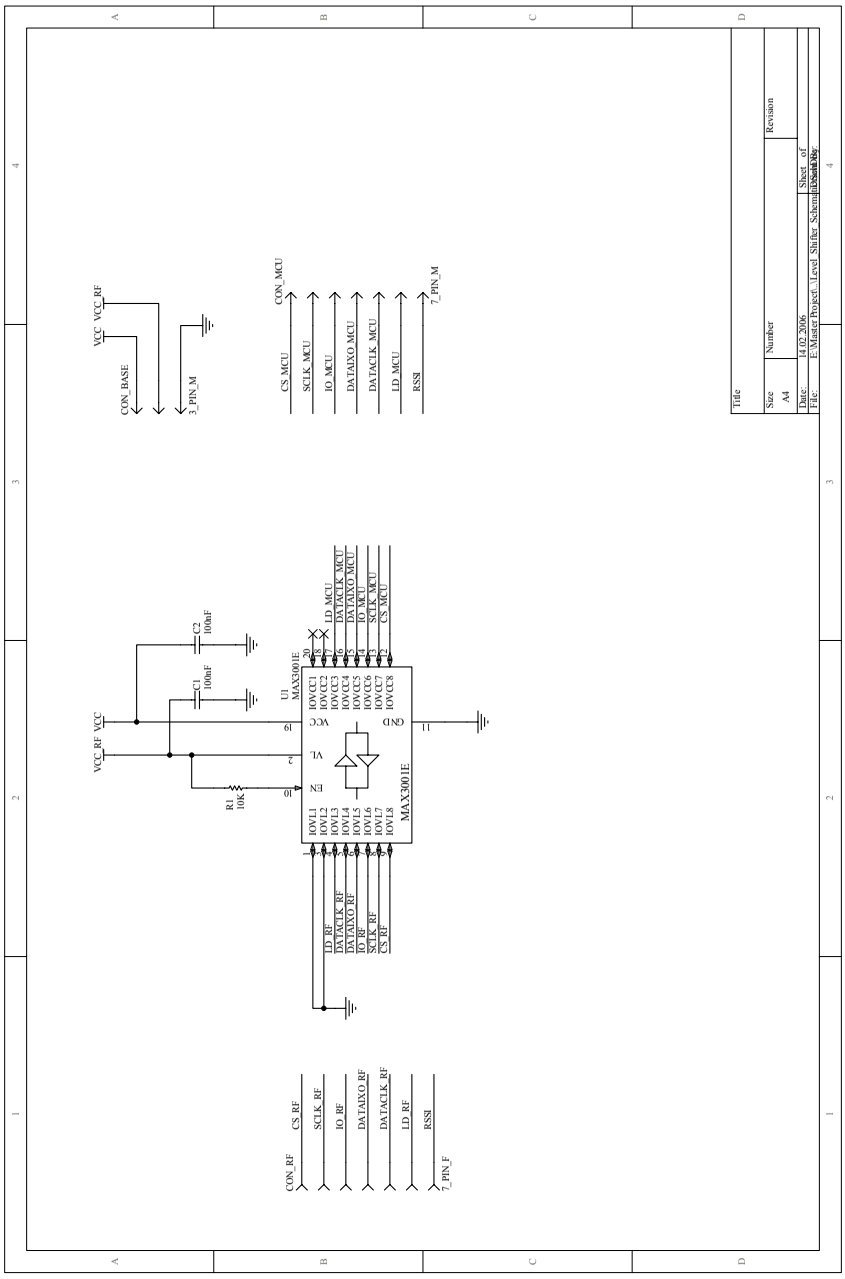
E.9 SENSOR: MCU



E.10 SENSOR: RF



E.11 SENSOR: LEVEL SHIFTER



F Loading picture in DDRAM

A Matlab®[1] function makes display data easier. The developper must:

1. create a black and white picture with the desired size, in bitmap format,
2. import the bitmap picture and run the function,
3. copy and past the text from the output of the function to the C - code,
4. use the appropriate function to display the picture on the LCD.

[1] commercial program for technical computing; `http://www.mathworks.com/`

G RF Protocol

The aim of this section is to give details on how the RF communication is implemented. The code applies to a **dsPIC30F4011** micro-controller (MCU). If another device is used, please set IO pins accordingly. In the following sections, only important remarks are made. For more information, consult corresponding source code file.

Common definitions and constants are in `rf_defs.h`.

G.1 IO lines

To interface the MICRF506, a total of 8 lines are required – 7 digital and 1 analog (for more details, refer to MICRF506 datasheet). These lines are defined in `rf_io_dspic.h`. Additional functions to set directions of bi-directional lines are also available in `rf_io_dspic.c`.

The RSSI signal is used to detect incoming signal. In the case of the dsPIC30F4011, the ADC must be correctly configured in main program. Detection threshold level is set in `rf_defs.h` under definition `RF_RSSI_THRESHOLD`.

G.2 Data link

Routines available in `rf_gen.h` allow proper interfacing between MCU and RF IC. Waveforms of required signals are given in the MICRF506 datasheet.

Functions `RF_WriteSingleRegister` and `RF_ReadSingleRegister` enable writing and reading to internal registers of the MICRF506.

To exchange data over RF, the DATAIXO and DATACLK of the MICRF506 are used. The DATACLK is controlled by the MICRF506 and the data interface is defined in such a way that all user actions should take place on falling edge of DATACLK. In the case of the dsPIC30F4011, the Change Notification (CN) interrupt is used. In the corresponding interrupt service routine (ISR), the DATACLK is sampled to ensure that only actions on falling edge are made.

G.3 Main services

All necessary functions needed to use the RF protocol are defined in the file `rf_service.c`. By including `rf_service.h` in a main program, one can access to the functions below:

- `RF_Init_Service` initializes IO lines, set priority of interrupts (only argument to specify in this function) and programs MICRF506 with default configuration
- `RF_RX_Mode` and `RF_TX_Mode` toggles between receive or transmit active modes of the RF IC
- `RF_TX_Power`, `RF_Powerdown_Mode` and `RF_Standby_Mode` allow power management of MICRF506
- `RF_Set_Local_ID` and `RF_Set_Local_Address` enable changing current default local parameters (though this is not recommended)
- `RF_Get_Sender_Address`, `RF_Get_Sender_ID` and `RF_Get_Frame_Type` give access to data extracted after a successful reception
- `RF_Get_Buffer_Pointer` returns a pointer to access payload with the number of bytes to read given by `RF_Get_Payload_Length`

Furthermore, `RF_Send_Packet` and `RF_Receive_Packet` are two essential functions to initiate communication. They are described in next sections.

G.4 TRANSMIT PROCEDURE

To transmit a packet over RF, just call `RF_Send_Packet` and provide necessary parameters:

- a pointer to the data buffer to be sent
- the number of bytes in this buffer to be sent
- the type of the packet
- the recipient's address
- last parameter to automatically power down after transmission or not

After all being encoded and put into a buffer, data is sent by activating CN interrupts. Finally a flag is set to inform user that all data have been sent. A length error code is returned by `RF_Send_Packet` if the number of bytes to sent exceeds that defined by frame structure.

G.5 RECEIVE PROCEDURE

Data can be received simply by calling `RF_Receive_Packet`. The main problem of a reception is to know whether there is an incoming signal. This is the role of the `RF_CHECK_RSSI` option. If no signal is present, `RF_Receive_Packet` will be automatically ended. On the other hand, if the `RF_SKIP_RSSI` option is used instead and no signal is present, then `RF_Receive_Packet` will constantly seek for a *SYNC*. The only way to force terminating this process is to modify an argument passed to this function. An example of how to modify this variable is by using a interrupt source (such a timer period match) that sets the argument to a value different from 0.

As in the transmit packet function, error codes are also output here. Errors include:

- RF_MANCHESTER_ERROR
- RF_LENGTH_ERROR
- RF_CRC_ERROR
- RF_ADDRESS_ERROR
- RF_RX_TIMEOUT
- RF_RSSI_ABSENT

Moreover, additional argument can automatically set RF IC to power down mode after reception.

G.6 FIRMWARE LIMITATIONS

This version of RF protocol implementation has some limitations. These are:

- MICRF506 setup is defined once at compilation level in `rf_setup.h`
- optimization for low level routines is required or else receive process does not decode data stream correctly – at this stage, *Optimize Level 3* for `rf_gen.c` is required in MPLAB C30 environment

G.7 EXAMPLE 1: SENDING A PACKET

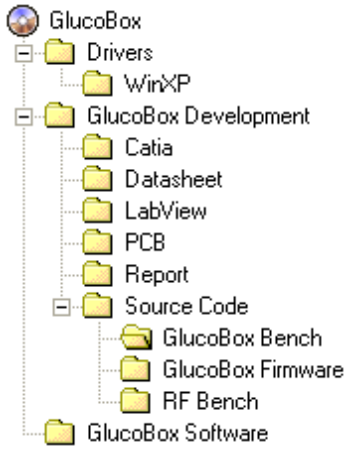
```
#include "rf_service.h"
unsigned char test_packet[]="Salut12345";
unsigned char error;
void main(void)
{
    RF_Init_Service(1);
    RF_Powerdown();
    RF_Set_TX_Power(6);
    while(1)
    {
        error = RF_Send_Packet(
            (uint8*)test_packet,
            5, RF_COMMAND_NOACK,
            RF_RECEIVER_ADDRESS,
            RF_AUTO_POWERDOWN_ON);

        DelayMs(2000);
    }
}
```

G.8 EXAMPLE 2: RECEIVING A PACKET

```
#include "rf_service.h"
unsigned char error, k;
unsigned int sum;
void main(void)
{
    RF_Init_Service(1);
    RF_Powerdown();
    while(1)
    {
        error = RF_Receive_Packet(RF_CHECK_RSSI, RF_AUTO_POWERDOWN_ON, 0);
        if(error == RF_NO_ERROR)
        {
            sum = 0;
            for (k=0; k<RF_Get_Payload_Length(); k++) {
                sum += *(RF_Get_Buffer_Pointer() + k);
            }
        }
        else
        {
            // in case of error, do something
        }
        DelayMs(2000);
    }
}
```

H Contents of Installation CD



Directory			Content
\Drivers	\WinXP		Drivers for GlucoBox Control Device
\GlucoBox Development	\Catia		Mechanical-drawing files
\GlucoBox Development	\Datasheet		General documentation
\GlucoBox Development	\LabView		LabView files for PO software
\GlucoBox Development	\PCB		Protel DXP (2004) files used for PCB design
\GlucoBox Development	\Report		LaTeX files of this project (including pictures)
\GlucoBox Development	\Source Code	\GlucoBox Bench	Files to build a new firmware (C code)
\GlucoBox Development	\Source Code	\GlucoBox Firmware	Current release of firmware
\GlucoBox Development	\Source Code	\RF Bench	Files to test RF part only (C code)
\GlucoBox Software			Installation files of GlucoBox Software